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The extraordinarily fine micrographs in color forming the cover design on this issue of Metal Progress *are of anodic films on aluminum as viewed under polarized light. They are of particular importance in the study of directional properties and recrystallization phenomena.*

Grain Orientation in Aluminum Revealed by Anodic Film

A LARGE NUMBER of technological problems arise from the presence of generalized or localized textures in metals. Certain peculiar behaviors in corroding media, and unexpected responses to chemical or electrolytic treatments are traceable to the distribution of grain orientations. "Earing" (in deep drawing) is primarily a problem of preferred grain orientations. Anisotropy of mechanical properties is related essentially to the orientation of the grain structure.

Research prompted by the necessity of controlling grain size leads from the general study of recrystallization to the specific exploration of the mechanism of rectification of crystallographic disorder. Investigations in this field often require knowledge of individual grain orientation in the sample under study.

Another important matter concerning mill practice is hot and cold plastic deformation. This leads to a variety of metallurgical quests. The grain of a plastically deformed metal undergoes some crystallographic disturbances which are reflected upon the orientation of the structure. Here also the determination of individual grain orientation proves to be useful in the study of these disturbances and orientations.

In such studies of plastic deformation, textures and recrystallization, the microscope is commonly used to examine the structure and make grain counts. It would be of advantage, from the standpoint of simplicity and rapidity, to determine grain *orientation* at the same time, provided an accurate method were available.

The method of etch pits, described by Barrett and Levenson in *Transactions* of the American Institute of Mining and Metallurgical Engineers, V. 137, 1940, p. 76, is simple and accurate. The application, however, is difficult when the grain diameter is of the order of 100μ or smaller, as is true for commercial aluminum sheet with good deep drawing characteristics. Etch pits are clear cut in pure aluminum. This has been demonstrated from time to time by several investigators and recently by Beaujard and Lacombe (*Journal* of the Institute of Metals, V. 74, 1947, p. 1). However, for certain aluminum alloys, etch pits are not clear in outline; because of selective attack and deposition of certain elements or compounds, the structure is not exposed in its entirety.

Revelation by Anodic Films — Grain orientation may be observed with a microscope if a layer of the metal is transformed into an optically active film — for example, by anodic oxidation of aluminum. In sensitive tint polarized light, selective wave-length extinction occurs and the color of the film changes with angular displacement. This

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phenomenon has been used by many, in particular by the petrographers, and has attracted the attention of metallurgists on several occasions. Recently, Beaujard and Lacombe* and K. Huber and A. Gaugler† demonstrated the optical anisotropy of anodic films on aluminum and the variation from grain to grain of the observed bi-refringence of the film.

The bi-refringence and the apparent relationship between the optical characteristics of the film and the substrate orientation had been observed in our laboratories for some time. We decided to investigate them further in an attempt to find a method that might enable rapid and accurate determinations of grain orientation.

For the method to be successful, several conditions must be fulfilled, namely:

1. Optical activity of the film.
2. Fixed structural relationship of grain and film.
3. Reproducibility of films.
4. Ability to determine the optical characteristics of the films and their relationship to the substrate orientation.

As a result of this research a technique has been worked out which will readily reveal individual grain orientations of aluminum and its commercial alloys. (As the work progresses, more information will be made available on the quantitative determination of grain orientations.) The method is applicable not only to aluminum, but also to any other metal, provided a film may be formed whose optical properties are related to the substrate orientation.

Preparation of Specimens

The film or coating is applied, in general, to a surface which has been polished either mechanically or electrolytically in the conventional manner for metallographic examination at high magnification.

Mechanical polishing may be performed according to a number of different techniques. The one applied for the samples which form the cover design on this issue of *Metal Progress* is as follows: After grinding successively on the No. 2, 0 and 000 metallographic emery papers, samples are polished on a rotating wheel covered with "Selvyt" polishing cloth, using "Carborundum Finishing Compound, Grade H-46 Medium", supplied by Canadian Carborundum Co., Ltd., of Niagara Falls, Ont. For the final polish Merck's "Reagent Grade Magnesium Oxide", low in sulphate, mixed with distilled water and screened through a 150-mesh sieve, is used on "Miracloth".

Electrolytic polishing often saves considerable time as compared to mechanical polishing and also may be used for preparation of the surface prior to the application of the anodic film. An electrolyte quite suitable for such samples as we are studying is of the following composition:

Orthophosphoric acid, 85%	70%
Distilled water	2.5%
Diethylene glycol monoethyl ether ("Carbitol")	26.5%
Hydrofluoric acid (48%)	1%

The electrolyte is maintained at 20° C. The sample to be polished is made the anode. Using a potential of 50 volts, the current density will rise after a few seconds immersion to about 6 amp. per sq.in. By proper agitation this should then drop to about 2½ amp. per sq.in. and be held there while polishing proceeds. The length of time required for polishing varies with the surface condition before electropolishing and may be from a few seconds to one or two minutes. Preliminary preparation of the specimen requires only that it be flat and free from very large surface scratches; the as-rolled surface is usually quite suitable as a starting point. A surface ground with No. 0 metallographic emery paper requires very little time to finish with this electrolytic treatment. For some samples it may be advantageous to carry the mechanical polishing past the emery paper stage in order to shorten the electropolishing time and thus produce a superior finish.

The electrolytic etch, if one chooses to call it such, is essentially an anodic treatment which produces a film of aluminum oxide on the surface of the metal. The electrolyte is the same as used for polishing; its temperature, 20° C., is also unchanged. The initial potential is approximately 20 volts. After the sample has been immersed a few seconds, the potential is raised slowly to 50 volts. On reaching 50 volts the current density will be found to be about 100 milliamperes per sq.in., which gradually drops with constant voltage to approximately 50 milliamperes per sq.in. in 20 min. During the entire cycle, agitation of the solution is maintained by a mechanical stirrer. The above current densities may be applied by controlling the amount of agitation. While a coating of sufficient thickness to reveal the grain structure is developed after 5 min. of etching, the treatment is usually prolonged for 20 min. for optimum results. At the end of the treatment the sample is washed, preferably in hot water, and dried. It is then ready for examination. As explained later, if the anodic treatment is pro-

**Journées des Etats de Surface*, Paris, October 1945, p. 44; Commission Technique des Etats et Propriétés de Surface des Métaux, Paris, 1944, p. 73.

†*Helvetica Chemica Acta*, V. 28, 1945, p. 146; *Experientia*, V. 3, No. 7, 1947, p. 227.

longed, striations appear on the oxide film, as shown in Fig. 2 at 300 × (upper right on cover design) and Fig. 5 on this page.

The film thus formed is uniform over the surface of any one grain. The thickness, however, varies from grain to grain and apparently is a function of the orientation of the grain. Moreover, there appears to be some relationship between the angle of a pore-like structure and the film thickness. It might be that the length of pore-like units is constant from grain to grain; when the pores are vertical to the polished face, the film would then reach its maximum thickness; when the pores are at an angle, the film accordingly would be thinner.

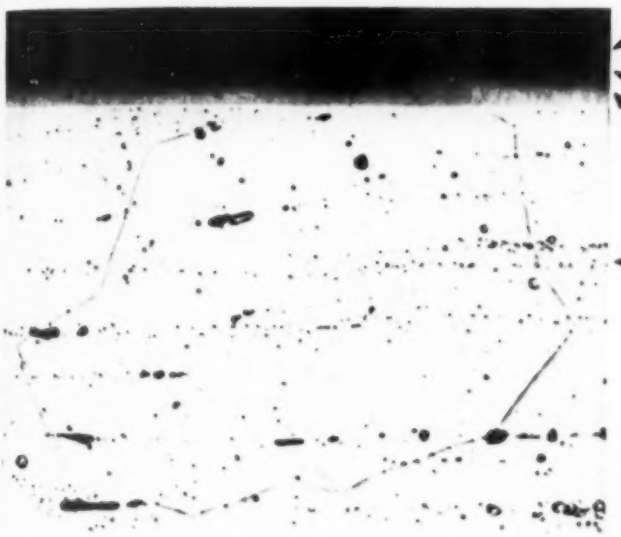

Fig. 5 — Cross Section of Anodic Coating Showing Shape and Depth of Striations in Anodic Coating Produced by Unduly Long Electrolytic Etching. 500×. Etched in diluted Tucker's reagent to show grain boundaries. The method of making the composite "Bostik 7008" mount for edge examination was described by André Hone in Metal Progress *for March 1947, p. 435*

Color Photography — The colored photomicrographs shown on the cover were taken on Ansco daylight film with a Bausch and Lomb research metallograph having a d.c. carbon arc lamp. Distilled water only was used in the cooling cell and no color correction filters were required. Exposure was of the order of 1/5 sec., with the aperture diaphragm set at 1.5. Processing of the film was according to the recommendations of the film manufacturer.

The photograph showing striated grains was printed according to the "Kodak Dye Transfer" process; the other three were printed on Ansco "Printon".

Mechanism of Revelation

The examination is carried out in polarized light with crossed nicols. Without the anodic film only a black field is obtained, aluminum being optically isotropic. With the anodic film, light is at least partly re-established and it varies in intensity from grain to grain. On rotating the microscope stage, each grain undergoes a gradual change of light intensity, which is repeated at approximately 90° increments. The anodic film introduces some retardation and it is evidently bi-refringent. The observed bi-refringence varies, however, from grain to grain and appears to be dependent upon the orientation of the grain.

If a magenta tint retardation plate is inserted in the optical system, and if there is not an anodic film on the sample, the wave lengths of the light reaching the ocular are complementary to some wave length usually close to mercury-green. When the sample is covered with an anodic film, the total retardation changes and a different set of complementary colors reaches the eyepiece. Since the apparent bi-refringence varies with grain orientation, each grain appears with its own color. The color changes upon rotation of the stage. The color effect obtained by a thin anodic film on a sample of superpurity aluminum with randomly oriented grains is shown in Fig. 1, at 300 × (the lower right corner of the cover — polarized light with crossed nicols and magenta tint insert).

If the time of electrolytic etching is prolonged past a certain point, a striated structure is observed (Fig. 2 — in upper right corner of the cover design — at 300 ×, lighted as described for Fig. 1.) On sectioning such a specimen, the striations were found to be grooves or channels, the depth of which was approximately equal to the width. This is illustrated in Fig. 5. The striations add further evidence as to the directional properties of the film itself. In Fig. 2 (upper right on the cover), the direction of the striations may appear, off-hand, to be the same for grains of a similar color, but by closer examination some differences may be observed. In fact, although both the interference colors and the direction of the striations are related to the orientation of the substrate, each indicates the orientation of a different plane.

In Fig. 5, it is worth noting that the characteristics of the anodic film vary with the substrate orientation. The depth, number and direction of the surface grooves change at the grain boundary.

Moreover, the pore-like structure changes sharply at the grain boundaries between the large central grain and its neighbors on right and left.

Qualitative Determinations of Orientation— The grain orientation is revealed at least qualitatively. Compare Fig. 1 (lower right on the cover) — superpurity aluminum without texture, each grain having a different orientation — with Fig. 3 (upper left on the cover) representing at 75 × some 99.8% aluminum with a strong localized texture. Although the grains are equiaxed and of uniform size, groups of grains belong to certain preferred orientations, as is indicated by the generally similar color of some regions. Localized textures such as this are the source of "orange peel" (although grain size is fine), of selective deep chemical attacks, and of heterogeneity of stress distribution.

This micrographic method is applicable not only to reveal localized or generalized textures, but to detect the initial stage of recrystallization in a plastically deformed system. In general, it is useful to bring to light any phenomenon which involves grain orientation. For instance, in chill-cast aluminum a twinned structure is sometimes obtained, as is clearly revealed in Fig. 4, at 75 × (the lower left view on the cover). The photomicrograph reveals that, within one single grain of crystallization, regions re-orient themselves in a manner suggestive of twinning.

Quantitative Determination of Orientation— Some semiquantitative determinations already have been obtained by using the striations (which are related to the crystallographic orientation of the substrate), or by fixing the extinction angle with reference to rolling direction or some similar axis of reference. Further information may be obtained from the interference color at 45° from the extinction angle; with the Bausch and Lomb metallograph the retardation may be measured by means of an elliptical vibration compensator, as described by A. F. Turner, J. R. Benford and W. J. McLean in *Economic Geology*, V. 40, January 1945, p. 18. This sometimes permits the measurement of the coordinates of the pole of one plane — as, for instance, (100).

X-Ray Identification of Sigma Phase in 25-20 Cr-Ni Stainless

By W. J. Barnett
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and A. R. Troiano
Professor of Metallurgy
University of Notre Dame

WITH THE WIDELY EXTENDED application of high-temperature alloys, the identification of the various phases that may occur or arise after long service has recently been the object of increased study. Of particular interest, in this connection, has been the occurrence and identification of the sigma phase, the brittle, complex Fe-Cr constituent in both ferritic and austenitic stainless steels.

Reported here is an X-ray technique developed for the identification of small amounts of the sigma in austenitic stainless steels, which alleviates the often uncertain results of the present metallographic procedures and, when operative, allows a positive identification of a given microconstituent. This technique was developed primarily for the identification of the unknown phase found by Clark and Freeman (*Transactions*, V. 38, 1947, p. 148) in fine-grained 25-20 low-silicon type of Cr-Ni-Fe alloy. By its use the unknown phase was positively identified as sigma.

A certain minimum concentration of a second phase is necessary for its characteristic lines to

appear on an X-ray diffraction pattern. If this second phase is present in the alloy in less than this required amount, it can be positively identified by increasing the effective concentration of this second phase on the surface of a sliver of metal used as test sample, whereupon the sensitivity of the X-ray diffraction method is increased and a clear pattern of the second phase may be obtained.

A specimen of 25-20 austenitic stainless steel containing the "unknown" phase was received through the courtesy of C. L. Clark of the Timken Roller Bearing Co. Its chemical analysis is as follows: 0.11% C, 0.58% Mn, 0.75% Si, 0.009% P, 0.010% S, 23.60% Cr and 20.65% Ni. The bar stock had been rolled into a 1-in. round and finished at a temperature sufficiently low to induce considerable strain hardening; after rolling it was normalized at 1700° F. and then heated at 1400° F. for 100 hr.

An X-ray sliver cut from the as-received stock was worked down to approximately $\frac{1}{32}$ in. diameter on fine emery paper and electrolytically etched for 5 min. at 4.25 volts and 0.7 amp. in an aqueous solution of ferric chloride (45 g. $FeCl_3 \cdot 6H_2O$ in 100 cc. H_2O). A nickel strip served as the cathode. Examination under the microscope revealed that large portions of the austenitic matrix were preferentially etched, leaving the particles of the unknown phase in relief. The photomicrographs illustrate the structure before and after the special etch described above.

A Debye pattern of the etched sliver (taken with chromium characteristic K-alpha radiation) definitely identified the unknown phase as sigma. The identification was completed by comparison with a diffraction pattern of a known 100% sigma alloy.

It is hoped that further applications of this technique, or modifications of it, will be applied to the identification of other unknown phases. The method is simple and rapid. The total time for preparation of the specimen should not normally exceed 15 min. For the specific experiment described here the method was relatively insensitive to the voltage and current but quite sensitive to the concentration of the electrolyte.

This work was performed in preparation for an extensive investigation of the precipitation of sigma and other phases in high-purity iron-chromium alloys and commercial alloys with iron-chromium base.

Fig. 1*a* — Conventional 10% KCN electrolytic etch

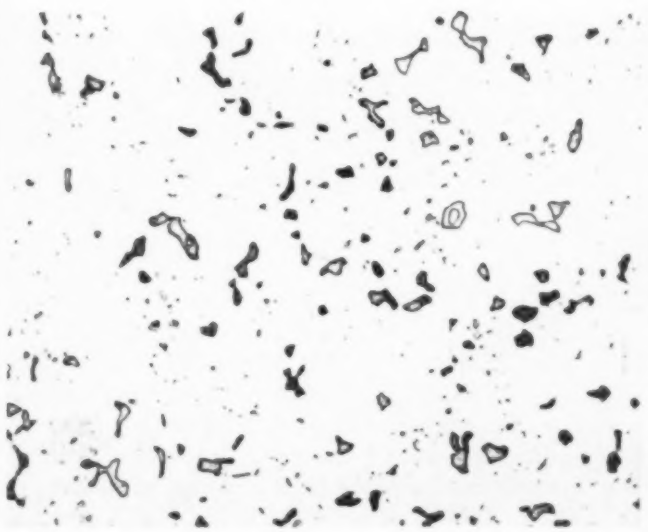

Fig. 1*b* — Special electrolytic etch described in text

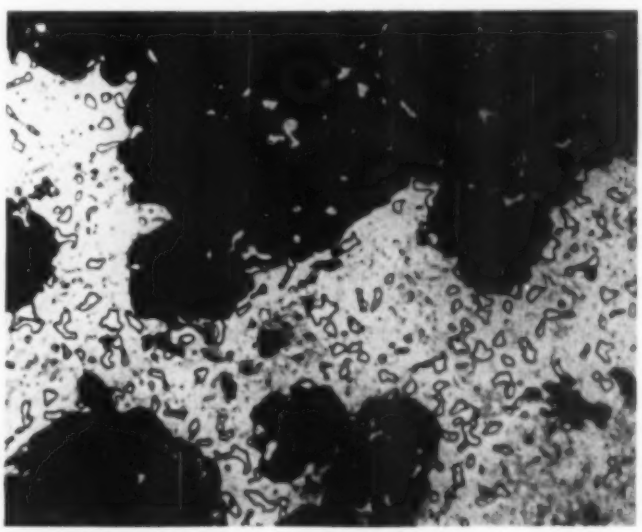

Fig. 1 — Sample of 25-20 Cr-Ni Stainless With Isolated Particles of Sigma Phase. 500×. The black areas of Fig. 1b represent relatively deep pits, the bottoms of which are out of focus. By changing the focus to reveal the base of each pit, a multitude of particles of the precipitate are found standing in relief — in much the same fashion as those that are evident in the plane of focus of the photomicrograph on the left

Preferential removal of groundmass of an alloy may leave a sufficiently high concentration of a second phase at the surface so that it can be positively identified by Debye X-ray diffraction pattern.

The Belgian originators of the process for electropolishing metallographic specimens describe the make-up of the "standard" solution of perchloric acid and denatured alcohol. It is capable of a good etch in 30 sec. They exhibit several examples of the results.

Rapid Electropolish and Etch

IT IS SEVEN OR EIGHT YEARS since the present authors first drew attention to electrolytic polishing in a report giving all the details published in the *Transactions* of the Royal Flemish Academy of Belgium (*Comptes Rendus* de la Koninklijke Vlaamsche Academie van Belgie) following an address at the session held April 13, 1940. Today this method is used by metallurgists in industry to a considerable extent. In America, for example, it has been used at least since 1942 as shown in a note describing practices in the metallurgical laboratory of the Denver and Rio Grande Western R.R. published in *Metal Progress* for August of that year.

We believe, however, that the method will be exploited more in the future because of its great simplicity and rapidity. Working in the prescribed limits of current density, one can obtain good results consistently, provided the electrolyte is stirred or agitated sufficiently.

The electrolyte is a solution of perchloric acid and ethyl alcohol denatured with ether (which probably plays no role in the process). The entire range of compositions of such solutions has been explored and it has been found that the optimum mixture consists of one part $HClO_4$ (sp.gr. 1.25, 20% solution) and four parts denatured ethanol, and this has been adopted as our "standard".

Other alcoholic solutions based on sulphuric acid, nitric acid, phosphoric acid, and ferric chloride (the latter being the best of the group) give some polishing action, but none compare with the standard solution given above.

Two other factors are of importance:

Current Density. Depending upon the metal or alloy, the current density should run between 2 to 6 amp. per sq.cm. (0.3 to 1 amp. per sq.in.). This corresponds to a potential drop of the order of 70 to 80 volts or more, depending upon not only the current density but the distance between electrodes.

Agitation of the Bath. Because of the excessive heat generated by the high current densities, it is necessary to agitate the electrolyte vigorously. If the bath is not stirred, enough heat is developed in the neighborhood of the anode to boil the solution, interrupting the flow of current and stopping the polish. In addition to brisk stirring, work on an industrial scale requires a generous volume of electrolyte and an adequate cooling arrangement.

Mechanism of the Action

The theory of the mechanism of electrolytic polishing is of interest. We intend to report later on an investigation of this subject and in the present article we will confine ourselves to stating four conclusions which we have drawn from it.

There are two theories on the subject: That of P. Jacquet, who attributes the polishing proper to the formation of an anodic film of high ohmic resistance, and that of W. C. Elmore, who maintains that the polishing is due to a concentration

By Albert De Sy
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and Herman Haemers
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gradient in the anodic film formed during electrolysis. The general form of a curve

$$I = f(v)$$

of current I versus voltage v starts with low current and voltage values, both values increasing with time until a maximum is reached, whereafter the current remains steady while anodic brightening occurs even though the voltage is materially increased — that is, the curve flattens out.

1. The potential drop developed when operating in the flat part of the curve, $I = f(v)$, is due to the anodic drop in potential. This was determined by local measurements of potential at the anode and cathode. It should be noted that the conditions under which our method of electrolytic polishing is conducted do not correspond to the level part of the curve $I = f(v)$.

2. Elmore's equation — that $i_o \sqrt{t}$ is constant, where i_o = current density, and t = time in sec. between the first application of current and the attainment of the final potential drop — has been verified and found to be exact. We found, however, that in using small values of i_o when operating on the flat part of the curve, scarcely any polishing was obtained, but rather an exaggerated attack. Along these lines, we found that the thickness of the high resistance anodic film should be from 25 to 40 microns for successful polishing. If the thickness was less than this value (as occurs for small values of i_o) then the sample was vigorously attacked.

3. For a solution to be suitable for electrolytic polishing, the anodic products should be quite soluble in the electrolyte. For example, in electropolishing iron by the De Sy-Haemers method, FeO_2 is formed and this is very soluble in alcohol.

4. Ether has no effect on the mechanism by which polishing occurs. Its presence in the alcohol is simply a matter of price; pure alcohol gives the same results.

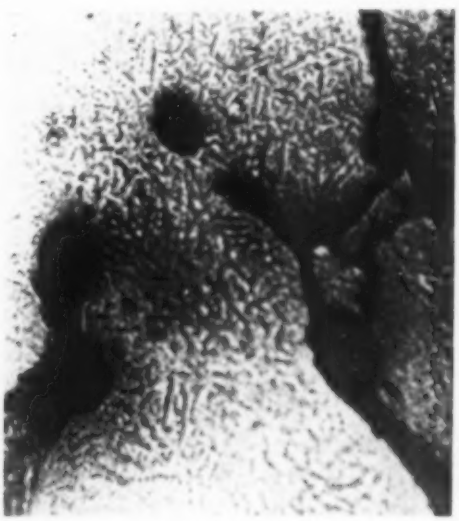
Applications

The standard solution (1 part 20% perchloric acid to 4 parts ethyl alcohol) is suitable for polishing a number of metals and alloys, such as iron, all grades of carbon steels, practically all types of special steels including high speed steels and 18-8 stainless steels, white cast iron, aluminum and all its alloys (except those containing more than 2% silicon), lead and lead-tin alloys, and certain zinc alloys. Examples of photomicrographs of specimens polished in perchloric-ethanol are shown in the accompanying half-tones.

Very Pure Aluminum, 900 ×

Duralumin*, 450 ×

Y Alloy†, 450 ×



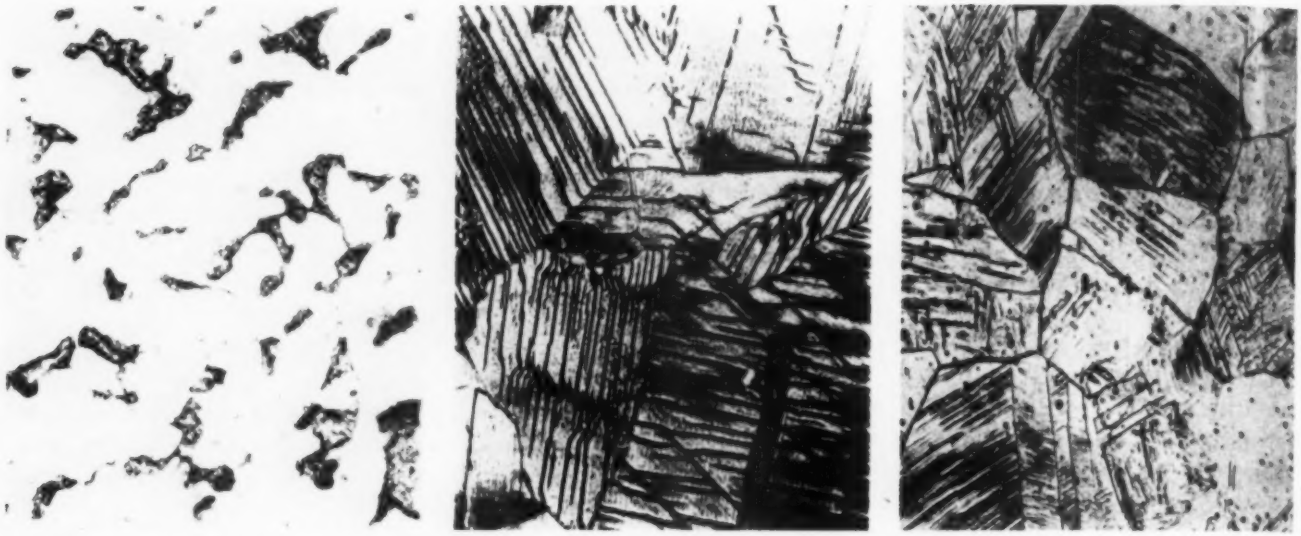
Aluminum and Aluminum Alloys; Samples Prepared on No. 0 Emery Paper, Polished 15 Sec. at 1.5 Amp. per Sq.Cm.

The only important variable to be considered in polishing such a wide variety of alloys is the current density; this should run between 0.5 and 6 amp. per sq.cm. for iron alloys, between 1 and 4 for aluminum alloys, and between 0.5 and 2 for lead, tin and zinc alloys.

Some investigators have found that some very mild steels and 18-8 stainless steels containing titanium will develop a number of black spots,

*Duralumin has 4% Cu, 0.5% Mg, 0.5% Mn.
†Y Alloy has 4% Cu, 1.5% Mg, 2% Ni.

Mild Steel (0.18% C) Hadfield's Steel (14% Mn) Stainless Steel (18-8)

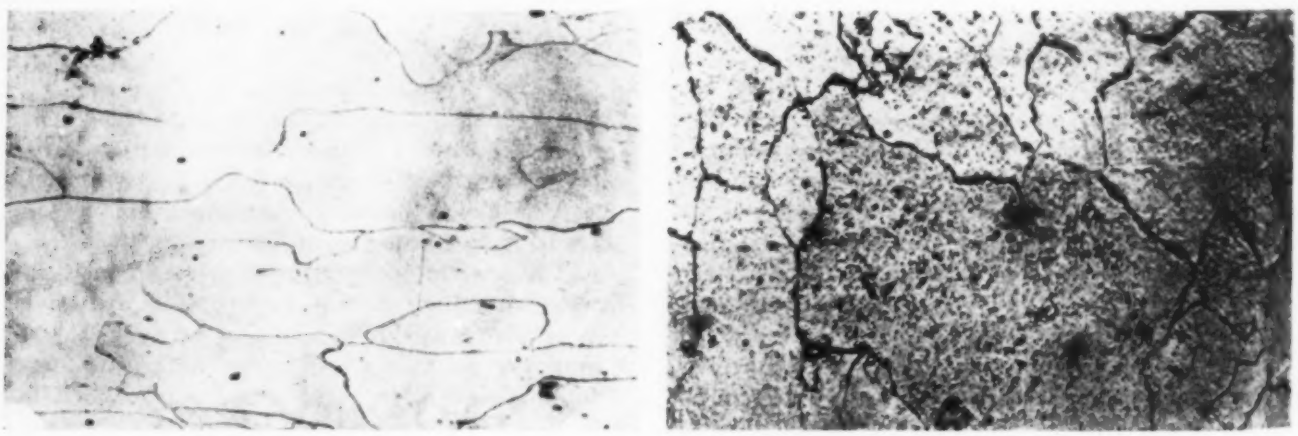


Micrographs of Steels at 450× Prepared on No. 1 Emery Paper and Polished 20 Sec. at 3 Amp. per Sq.Cm.

having the appearance of pits, when polished by this technique. It is evident, however, that such defects are inherent to the metal and not a result of the polishing method (though, to be sure, they are accentuated by electrolysis). This should be regarded as an advantage of the method, for is it not one of the purposes of micrographic inspection to reveal defects in a metal, rather than cover them up?

In the very low carbon "steels", such as Armco iron, the pits are particularly numerous if the metal has been deoxidized with aluminum. This is easily explained. Since electrolytic polishing is an anodic dissolution, solubility in itself is not a decisive factor, but the important point is rather the potential difference between the base metal and the second phase (whether it is a constituent or an impurity).

This point is worthy of further discussion. Two cases can be distinguished: Either the second phase is anodic or less noble, or it is cathodic or more noble. In the first case the second phase will be preferentially attacked and the intensity of this attack will be in direct proportion to the potential of the local cell; thus, silicon selectively dissolves in aluminum-silicon alloys. In the second case the base metal is deeply attacked around the more noble inclusion. This happens in the base metal surrounding a graphite lamella (in gray cast iron or malleable iron), or around a nonmetallic inclusion such as Al_2O_3 or SiO_2. Thus the presence of the second phase is exaggerated, the more so when



Two Micrographs of Ingot Iron, Illustrating Differences in Inclusions (Deoxidation Practices). Both samples prepared on No. 1 emery paper, polished 20 sec. at 2 amp. per sq.cm. 500×. At left is iron deoxidized by slag action in furnace; at right is iron deoxidized with aluminum

current density is high or electrolysis is long continued. Intermetallic compounds can be less noble (for example, $CuAl_2$ in aluminum-copper alloys) or more noble (carbides in iron or Al_7Mn in aluminum-manganese alloys).

The lower pair of figures on p. 370 show the microstructure of two grades of Armco iron (99.9% pure). The first was melted in an open-hearth, deoxidized by diffusion under a limey slag, and required only a small addition of aluminum. On the other hand, the second, at right, was melted in a high frequency induction furnace with no slag covering and was deoxidized with a large amount of aluminum (0.24%). Comparison of the two micrographs is instructive.

We believe, therefore, that electrolytic polishing is especially suited to the preparation and examination of extra mild steels. In the same way we feel that the method is particularly well adapted to estimate the degree of purity of so-called pure aluminum.

Naturally, if it is desired to repress an exaggeration of nonmetallic inclusions, the current density and etching time can be cut down, but this means that the sample should be given some preliminary preparation by hand on polishing wheels or on emery papers (0 to 1F for iron alloys and 00 to 0 for aluminum alloys).

Danger of Explosion — It has been pointed out occasionally that the perchloric acid in these electrolytes is a potential explosive. For the standard solution described above, the danger is practically nil. We have consistently removed samples during electrolysis to see whether the sparking would cause an explosion; nothing ever happened even though the specimens were mounted in bakelite. (Mounting in bakelite actually represents poor practice as far as electropolishing of the metallic sample is concerned. Such tests did, however, set up a vigorous reaction between the bakelite and the solution, and the attack of the bakelite was accompanied by a slight crackling.)

It has also been suggested that any contact between bismuth and perchloric acid solutions is dangerous. We have never noticed the least indication of danger with the recommended electrolyte.

Preparation of the solutions requires no special precautions; only a small amount of heat is developed on mixing, since the total amount of pure perchloric acid is not in excess of 4%.

During the polishing of iron-bearing samples, the perchloric acid dissociates and the solution will be spent after considerable use, being converted to ferric chloride and alcohol. Even in this state the bath will still polish (for the reasons outlined in the above paragraphs discussing "theory"). The results, however, are mediocre.

This department, "Bits and Pieces", welcomes notes concerning new ways of doing things to metals, either in shop or laboratory. An book of your choosing (other than the Metals Handbook) is the reward for a publishable item.

Bits and Pieces

Marking of Lucite Mounts

NUMEROUS suggestions for identifying lucite metallographic mounts have been considered in previous issues of *Metal Progress*. Here at Cleveland Graphite Bronze we find that ink made of methylene chloride with a little dye serves very well. The ink is applied with a "Speedball" pen and dries instantly. Since the methylene chloride is a solvent for lucite, the marking is permanent and is unaffected by subsequent immersion in an etching solution.

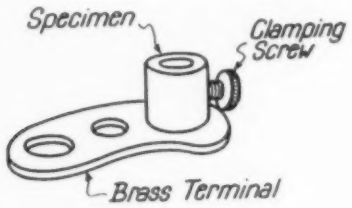
Methyl violet mixed with methylene chloride is very satisfactory. In fact, other dyes may be used and may form a ready means of identifying different classes of alloys. The markings resist erasure and any ordinary abuse encountered in the laboratory. (JOSEPH F. CERNESS, metallurgist, The Cleveland Graphite Bronze Co.)

Convenient Temporary Mount

TROUBLE has often been experienced in making temporary mounts for small metallic specimens — say from 0.07 to 0.12 in. diameter. This is especially true for preparing the sample for hardness testing with the diamond penetrator, owing to the nature of the examination and test — that is, the type of specimen being in cross section. This difficulty has been overcome by dismantling an ordinary 5-amp. "one way" local switch and making a small support from one of

the terminals. This is shown in the adjoining sketch.

The specimen is inserted into the terminal just as the electrical wire is fitted, the screw is then tightened, thus holding the specimen firmly.



The specimen is then sawed off flush with the top and bottom of the holder, and the surface prepared for microexamination or hardness testing in the usual way. (HENRY THOMPSON, Research Department, British Ministry of Supply, Steelworks, Barrow in Furness)

Etchant for Welds

DURING some work on recrystallization and annealing of 52S aluminum alloy for Reynolds Metals Co., it became necessary to reveal the crystals of the treated metal, whose surface had originally been in the "cold rolled polished" condition. Various of the listed etches were tried, but none were able to provide sufficient grain contrast. Experimentation showed that a solution containing one third each of water, hydrochloric acid and hydrofluoric acid would give the desired results after a few minutes' immersion. Directed reflections from the facets of the randomly oriented grains caused pronounced contrast. When the solution had lost its strength, addition of hydrofluoric acid replenished it. This was possible only once or twice.

Recently, at the Naval Air Experimental Station, the same solution was tried on seamwelds in 2S, 3S, 52S and 61S aluminum alloys. The crystal structure of polished cross sections was revealed with more than sufficient detail for examination and photography at 13 diameters. This detail also was obtained by oriented reflections from the crystal facets.

We next decided to adopt the etch for photomicrographic specimens. The original solution was diluted with three parts of water making the working composition 10 parts of water and one part of each of the acids. Figures 1 and 2 at 500 × depict 24S when etched with this solution. Intrusion of the alcladding into the weld nugget is shown in Fig. 1, while Fig. 2 illustrates the grain contrast obtainable with this solution on 24S-T sheet. When used to etch surfaces for microscopic examination, the detail is portrayed by differential etching of lines and areas of varying impurities. (GERARD H. BOSS, Aero Materials Laboratory, Philadelphia Navy Yard)

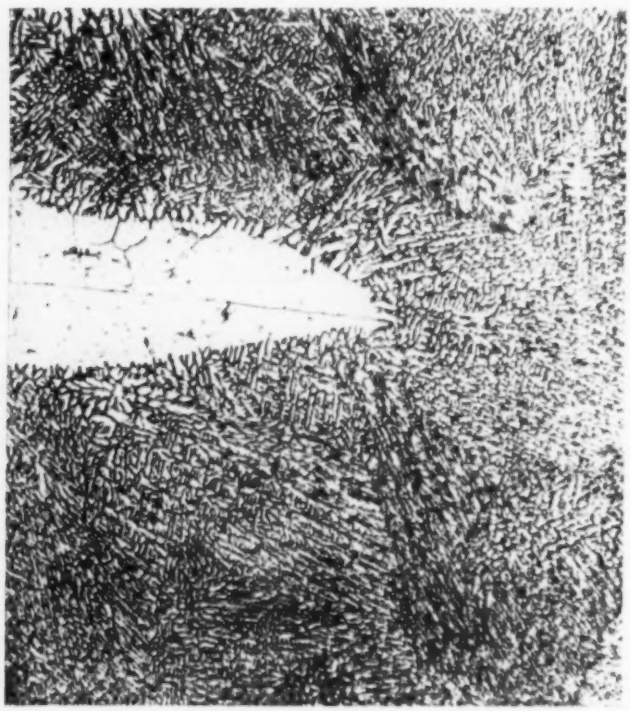


Fig. 1 — Intrusion of Pure Aluminum From Cladding Into Weld Nugget in Alclad 24S Sheet. 500 ×

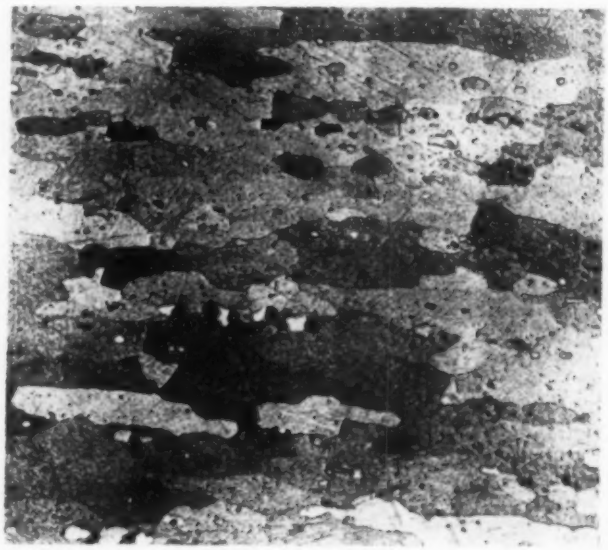
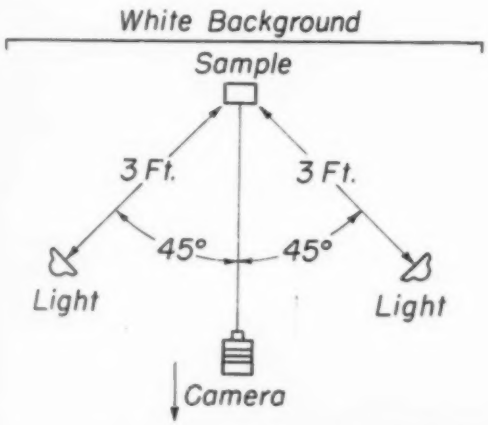
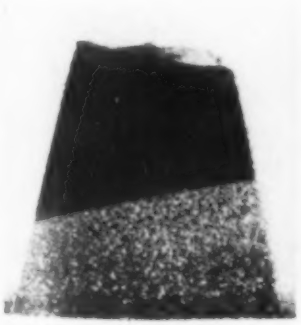


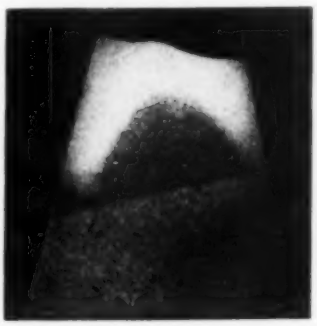
Fig. 2 — Grain Contrast (500 ×) on Etched Surface of 24S-T Sheet

Proper Photography of Hardened Zones

MANY STEEL SAMPLES containing hard and soft areas may be best differentiated on prepared surfaces, etched in picral or nital, by using reflected light from a diffused source set up similar to the right-hand sketch of the pair shown herewith. The two macrographs are of the same sample and demonstrate the differences obtained by a direct photograph (camera set normal to the object's surface) as compared to setting either the sample or camera at an appropriate angle so that the hardened surface reflects light from the diffused source. General Electric R-2 Photoflood lamps were used. This technique makes the fully hardened portion, which was not darkened by etching, appear white (as shown at the right), whereas the straight-away method of photography makes the hardened area appear dark and gives a false impression (as shown in the left photographic illustration). (JOHN J. GIBBONS, photographer, Metallurgical Dept., Carnegie-Illinois Steel Corp., Youngstown District Works)







Rapid Mounting of Specimens

OCCASIONALLY it is necessary to mount a few specimens in a hurry, for a fast microscopic check, and I have found a simple way of doubling the speed of the ordinary method. First of all a few alterations have to be made in the standard (Buehler) equipment:

1. Machine the base plug to ¼ in.
2. Make a second base plug of the above size.
3. Remove about 2 in. on center plug for clearance.

We are now ready to mount our samples. Proceed as in the usual manner for making mounted specimens, but pour only 17 cc. of bakelite or other plastic into the mold. For clarification we will call this our "primary" mount. Next place your second base plug over your primary mount and duplicate the previous procedure. This is called our "secondary" mount.

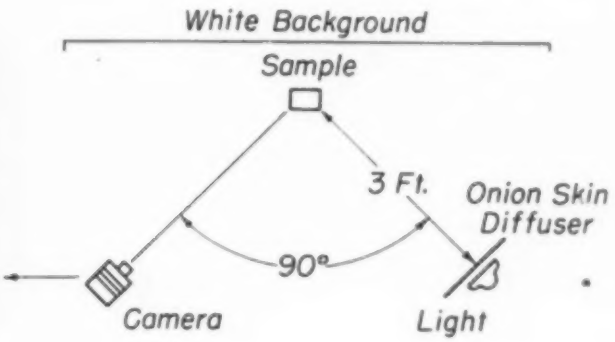
We now place the ram plug with hole for the thermometer into position, put on the heating jacket and apply the pressure. Maintain pressure at 7500 psi. until the temperature has reached 250° F. Cool to 150° F. and remove the mounts. You now have two ½-in. mounts which are satisfactory for all practical purposes. Time elapsed from start to finish, 20 min.

NOTE: It will be a simple job to make a container that will hold about 17 cc. of bakelite. 1 cc. of loose bakelite equals 0.02 in. molded. (T. J. LEPITO, Materials Control Laboratory, Pratt & Whitney Aircraft Division)

Grease Guard

MANY OF US no doubt have had the annoying experience of brushing or leaning against the grease-covered lead threads for the adjustable cross-head on a Baldwin-Southwark testing machine.

We solved this problem by slipping a two-foot length of four-inch stovepipe over the threaded column as a cover and allowing it to ride with the cross-head. The top edge was flared out slightly to prevent possible catching on the threads when raising the movable head. A coat of paint to match the machine completes the job. (T. S. HOWALD, research assistant, Chase Brass & Copper Co.)



Grand Prize; 1947

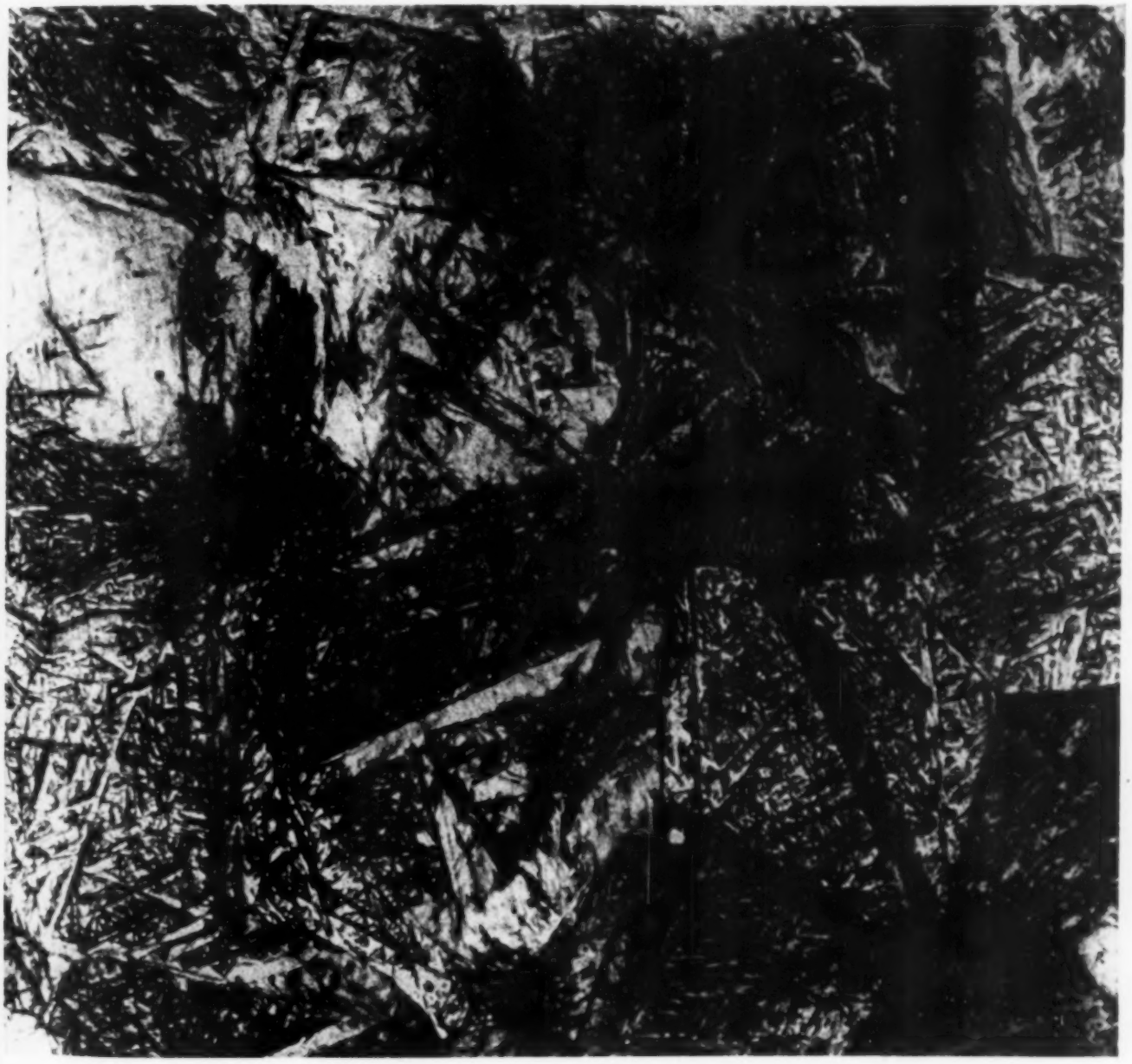
Subzero Transformation of Austenite

By R. H. Hays
Metallographer
Caterpillar Tractor Co., Peoria, Ill.

As Quenched From 2250° F.

A.S.M. Metallographic Exhibit

All Indicated Transformation of Austenite to Martensite Was Produced by Localized Expansion of Surface, as no Additional Etch or Other Preparation Was Employed. The material was intentionally overheated to place all complex alloy carbides in solution with austenite. Analysis of sample: 5% Cr, 1% Mo, 1% C and 0.8% Mn. Etched after quench with chromic acid and aqua regia. 200 ×



Identical Area After Cooling to 110° F. Below Zero

Survival in the Atomic Age

Extracts from Report* by the President's Air Policy Commission, **Thomas K. Finletter** (chairman), **George P. Baker**, **Palmer Hoyt**, **John A. McCone** and **Arthur D. Whiteside**

WHILE the President's instructions required the broadest kind of survey of all phases of aviation, we take up first the problem of the national security.

We believe that the United States will be secure in the absolute sense only if the institution of war is abolished under a regime of law. World peace, however, is not yet in sight. Even the most optimistic view of the records of the United Nations organization does not assure us that it will develop in time the necessary authority and power to prevent another war.

Where does security lie in a world in which war is the final resort for the settlement of international disputes? While armaments are not a guarantee of peace, reluctantly this Commission has come to the conclusion that relative security is to be found only in a policy of arming the United States so strongly that other nations will hesitate to attack because we will be able to smash the assault and because of the violence of the immediate counterattack.

We believe that the defense of the United States must be based on air power. No challenging naval power exists today or can possibly exist for many years to come, except from the development of new submarine techniques. Atomic weapons will not long remain our monopoly but it would be an unreasonable risk to rely on other nations not having atomic weapons in quantity by the end of 1952. As to other more conventional weapons, no nation is likely to have in the immediate future piloted aircraft capable of getting air supremacy over the U. S. mainland. While guided supersonic missiles of the German V-2 type are now impossible to intercept, such missiles of long range will probably not be available in operational form for from 10 to 25 years. Subsonic guided missiles with a 5000-mile range and capable of being directed toward a city can be developed into mass-production stage within 5 years. (These would be subject to a high rate of interception by a well-prepared defense, but projected experience from the last war indicates that at least one third would get through in the early stages of the attack.)

The Commission thus fixes the date by which we should have an air arm capable of dealing with a possible atomic attack at Jan. 1, 1953. The force we need by that date must have complicated defensive equipment (fighter planes, ground defense, radar warnings) but we also must have in being and ready for immediate action a counteroffensive force built around a fleet of bombers, accompanying planes, and long-range missiles. It must be assumed that the war will start with direct attack, without warning, with atomic weapons, and of a violence difficult to imagine. Mass destruction would probably be followed by air-borne invasion.

The present Air Force consists of about 462,000 personnel with 580 heavy bombers, 2300 fighters and 7920 other aircraft in active status, divided into 55 groups, and backed up by a reserve of 12,800 usable aircraft from World War II. This is supplemented by 5793 front-line planes operated by the Navy, plus about 5100 in support.

We conclude that this establishment could not carry out the missions assigned to it as of Jan. 1, 1953, because it is lacking in essential air units for effective combat action. By that time the minimum force must be built up to 12,400 modern planes in 70 combat groups, 22 special squadrons, 27 National Guard Groups (3212 front-line aircraft) and 34 groups of Air Reserve, all (with the exception of the last) equipped, trained and ready for immediate action. This plan includes 700 very heavy bombers for long range. Only by using the very best equipment and the latest techniques will so small a force be effective. (It is 5% of the number engaged in European combat during the war.)

[Such a project for rebuilding the air arm involves many considerations concerning the military organization, aircraft and accessories manufacturing industry, research into airframes and propulsion, and civil aviation, all of which are dealt with comprehensively in the report.]

The increased activities must be started at once and completed by the end of 1952. The cost will be considerable. Annual appropriations for the national defense program of $10.1 billion in 1947-48 fiscal year should be increased by $1.3 billion annually, reaching an estimated $18 billion in the 1952 budget, substantially all of the increase being for research, development and construction of new types of aircraft and propulsion, modernizing of Army and Navy Reserves, and the increase in necessary flying and ground personnel.

This Commission does not believe that we will ever have an adequate military establishment unless the people of the country know fully what the international military and political situation is, what kind and size of military, air and naval force is necessary if we are to be ready for that situation, and how much it will cost to have this force. These facts are known by all foreign governments, but there is now no procedure in our own government for systematically informing our people about them.

*"Survival in the Air Age", issued Jan. 1, 1948; 166 pages; U. S. Government Printing Office; price 75¢. The result of a five-month study.

Presentation of verbatim extracts from important contemporary documents concerning atomic energy does not imply that the Editor agrees with the opinions quoted, nor that they are expressions of A.S.M. policy.

The third of a series of studies of fresh cleavage planes in brittle metals, where the untouched facets are examined under high power microscope for evidence concerning the mechanism of fracture.

Fractographic Structures in Antimony

By C. A. Zapffe
and F. K. Landgraf, Jr.
Baltimore, Md.

TWO PREVIOUS PAPERS in *Metal Progress* for August 1946 and March 1947 presented the cleavage patterns found at high magnification in bismuth and in zinc, respectively, using the microscope technique referred to as "fractography". Here we shall examine patterns found in antimony, another metallic element which readily develops facets especially suited to the technique. The facts and photograph presented were accumulated during a study, in the senior author's laboratory, sponsored by the Office of Naval Research (to which acknowledgment is due for permission to publish).

Like bismuth, antimony has a rhombohedral (A7) structure with each atom surrounded by three nearest neighbors. Its lattice constant is $a = 4.4976$Å at 25° C. and its axial angle is 57° 6.5′. Its general occurrence is massive, lamellar, and markedly cleavable. Cleavage on the hexagonal axes (0001) is highly perfect, but secondary cleavages also occur, as will be demonstrated in this paper. The hardness of antimony is 3 to 3.5 on Mohs' scale; its density is 6.22 g. per cc.; its luster metallic, color and streak tin white. In common with rhombohedral crystals, antimony twins on {01$\bar{1}$2}. Slip, which is much less common than twinning in antimony, occurs on the basal cleavage plane.

Material — Specimens were prepared from commercial "C.P. Antimony Lump" having the following analysis: 99.83% Sb, 0.04% S, 0.035% As, 0.035% Pb, 0.015% Fe and 0.01% Cu. Fractographs were obtained from this material, as purchased, and from remelted and specially treated samples, as will be described.

By means of a specially designed "fractographic stage" built by the Bausch and Lomb Optical Co., the specimens were mounted, studied, and photographed in the as-fractured condition (unetched and unpolished) as described in the previous papers, and more in detail in the original paper "Fractography — a New Tool for Metallurgical Research", by C. A. Zapffe and M. Clogg, Jr., *Transactions* ASM, V. 34, 1945, p. 71. Effects of light and shadow were attained with oblique illumination, which serves here in photographic principle much as an etching agent does in conventional metallography in affording differentiation of surface contour.

If antimony is fractured slowly, as by squeezing in a vise, local rupturing forces are held to a minimum by dissipation along planes of greatest weakness, and cleavage is primarily basal. Under conditions of more rapid fracture, as by impact, local forces may develop which also exceed cohesion across other planes, and a great proportion of the cleavage may be secondary, along pyramidal planes. Two distinct types develop, which will now be separately illustrated.

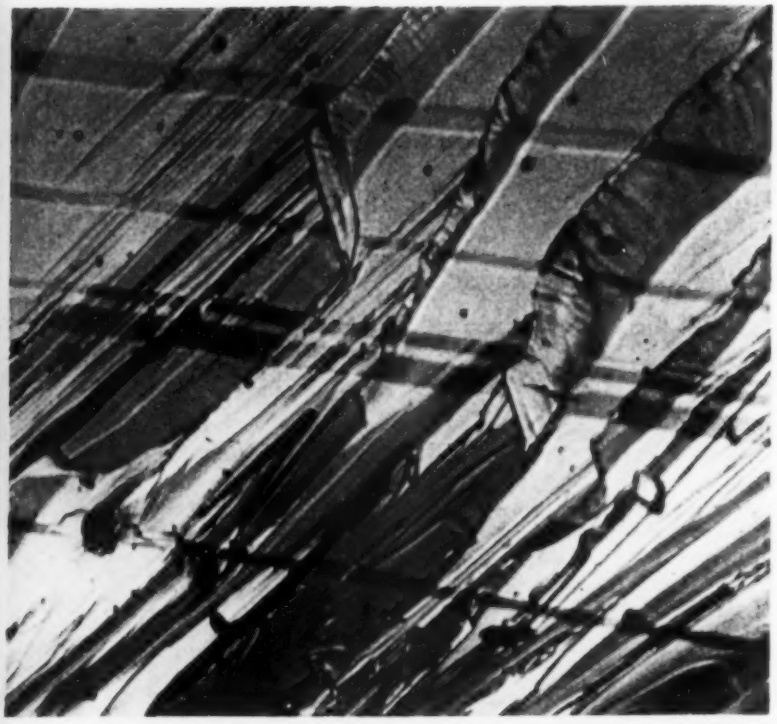


Fig. 1 — Primary Cleavage of Antimony, Showing Twin Bands (Parallel Markings Slightly Inclined to Horizontal) Overlying a Succession of Basal Facets. Pure metal, as cast. 400×

Primary Cleavage (Basal) — First, we shall discuss primary cleavage patterns and the structures observed upon the (0001) plane. Figure 1 presents a typical example. Cleavage here is principally basal, though imperfectly so, skipping across a small range of lamellar levels. Overlying the succession of basal facets are markings which, on the basis of established crystallographic characteristics of antimony, can be rather certainly identified as twin bands (the parallel bands slightly inclined to horizontal). The crystallographic indices cannot yet be ascertained, since only those of one direction show.

Another striking view of these markings, henceforth presumed to be twin bands, which abound on basal cleavage facets, appears as dark streaks diagonally across Fig. 2. Here a second and even a third set of the twin family can be seen as brightly illuminated lines having the expected equilateral triangular placement for this system. Also note that the bands cross the badly deformed area near the center of the fractograph. In general, fractographs concern intragranular structures, the grain boundaries lying well out of the field of view, and Fig. 2 undoubtedly shows a grain which first developed twins in plastic response to deformation, then failed by cleavage.

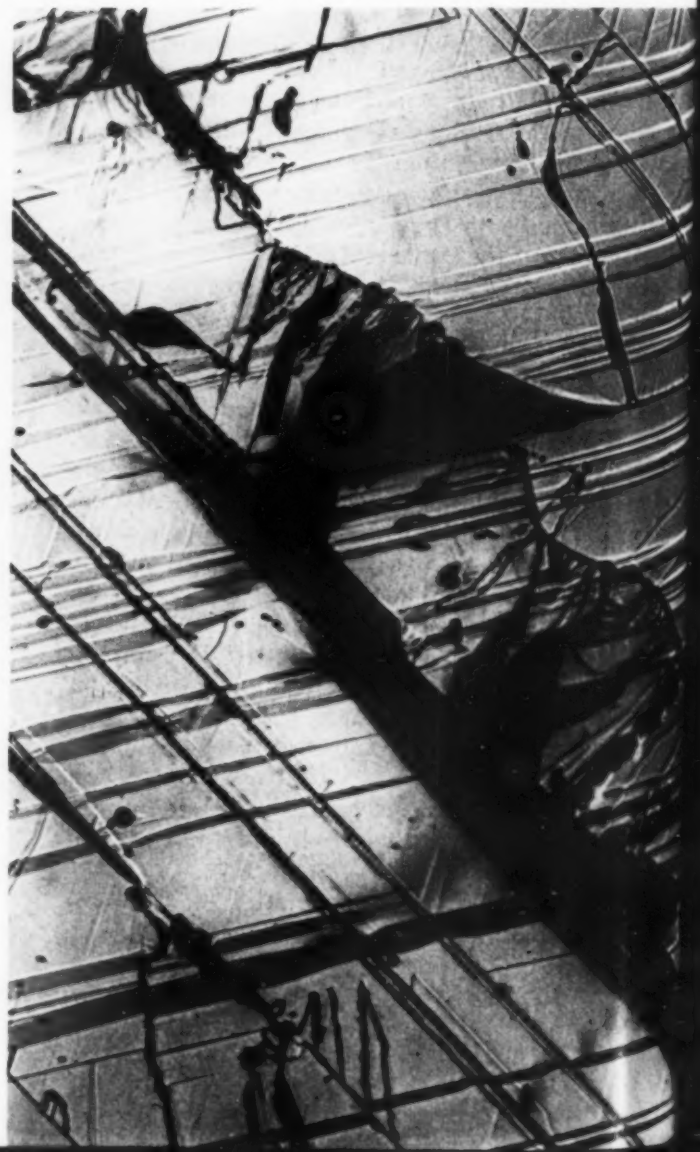


Fig. 2 — Primary Cleavage of Antimony Revealing All Three Directional Sets of the Twin Family. Note twins crossing disorganized area near center. Pure antimony, as cast. 50×

Twins Within Twins

Occasionally a complex twin structure is observed, such as that in Fig. 3. Taken at very high magnification, the fractograph shows what appears to be twins within twins. However, besides the expected occurrence of 60° markings, there are also markings at 90°. This would seem to require twinning on at least two families of planes, since any single pyramidal or prismatic set would develop only 60° traces on (0001). While the present preliminary study does not attempt to solve rigorously the patterns that are presented, the suggestion will be made that this is an instance of combined Type I $\{10\bar{1}2\}$ and Type II $\{11\bar{2}2\}$ pyramidal twinning. For example, $(10\bar{1}2)$ intersects $(1\bar{2}12)$ at 90° on (0001). (See

"Structure of Metals", by C. S. Barrett. McGraw-Hill Book Co., 1943.)

Lastly, there is a particularly impressive display of twinning in Fig. 4. Note the "tailing" of the gray bands as they approach intersection with the more steeply faulted regions, indicating their subsequent formation. Striations are also definitely visible in one direction, and suggested in the other two. In the investigation of bismuth (*Metal Progress* for August 1946) striae were subtle surface markings ascribed to reorganization of a thin surface layer at the instant of separation by cleavage, the newly formed surface possibly experiencing a transient liquid-like condition which leaves a superficial overlayer having crystallographic conformation. Here again the authors prefer this explanation to the possible alternative that the markings represent either slip or twinning on a fine scale, and the probability of striae representing a stress pattern seems unlikely because of the crystallographic conformity of the markings and their three-directional occurrence at angles of 120, 240, and 360°.

Transition Structure — Particularly under conditions of rapid application of stress, where local resolution of force may develop at an unfavorable angle to the basal plane and in sufficient magnitude to overcome cohesion across another family of planes, a condition of secondary cleavage can develop in antimony.

Preceding fractographs contain evidence of secondary cleavage, but only over minute interlamellar distances. In Fig. 5, the digression from the flat, basal cleavage is more pronounced, the fracture having covered considerable travel at an angle to (0001). This it does by step-wise separation along alternating families of basal and pyramidal planes. Twins traverse this field and, by their offset from straightline progression, indicate

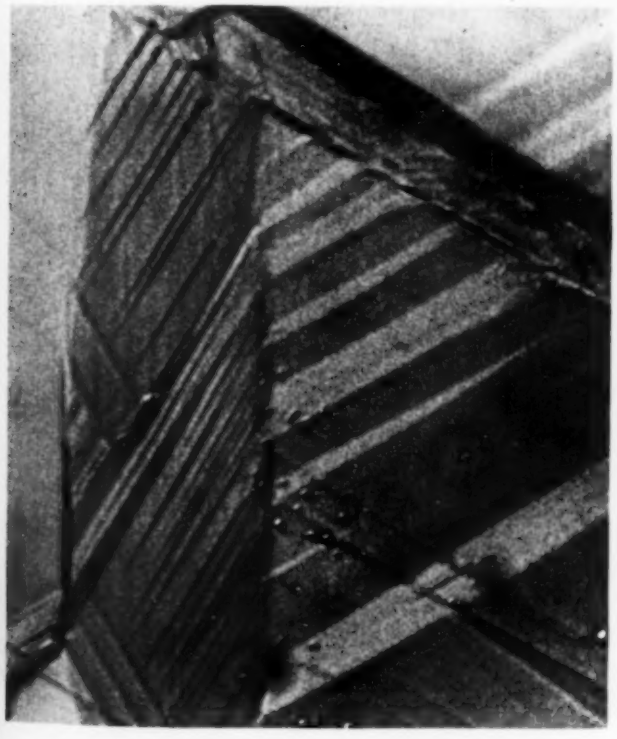


Fig. 3 — Primary Cleavage of Antimony Revealing Twins Within Twins at High Magnification. Note the numerous markings, both cleavage and twin, some at 90° angles, in contrast to the expected 60°. Pure metal, as cast. 3000×

Fig. 4 — Primary Cleavage of Antimony Showing Gray Twin Bands "Tailing Down" as They Approach Intersection With Grosser Markings, Which May Be Either Cleavages or Twins. These gray bands are formed subsequent to the grosser markings. Striae also markedly overlie all structures; and these are presumed to represent final phenomena of surface tension at the instant of cleavage. Sample of pure antimony superheated to 650° C. in purified helium and furnace cooled. 1250×

the considerable succession of basal levels exposed by the fracture. A grain boundary is also evident at the left edge of the field as a wandering line beyond which the structures lie out of focus.

Secondary Cleavage — For some unknown reason, secondary cleavage is infrequently mentioned in crystallographic descriptions of these metals. In the present study, specimens were found having observable pyramidal facets on three contiguous sides. Fractographs from each side were mounted on a solid model, and the system was studied with respect to the traces of the various markings on each of the three faces. The pyramidal cleavage is clearly not the twinning pyramid, but measures goniometrically to be $\{11\bar{2}1\}$, or $\{10\bar{1}1\}$. Thus, cleavage occurs primarily along the base and secondarily along the faces of a pyramid {hk.1} having unitary intercepts, while twinning occurs along the faces of a similar pyramidal form having but a half-unit intercept on the *C*-axis.

Fig. 5 — Combined Primary and Secondary Cleavage in Antimony. The twin bands progressing across the whole fracture face give indication of the numerous basal levels exposed by the fracture as it climbed from one to another by secondary separation on pyramidal planes. A grain boundary is also evident at the left edge of the view, beyond which lie structures having separate orientation and proceeding rapidly out of focus. 300×

In Fig. 6, one observes a facet of pyramidal cleavage. Basal cleavage seems absent, except possibly on a submicroscopic scale. The facet photographed is rendered simultaneously in profile by the wide, black band denoting pyramidal cleavage on one of the two intersecting face groups. The strongly marked parallel lines measure about 35° with the edge, in keeping with $\{10\bar{1}2\}$ twinning

Fig. 6 — Secondary Cleavage on a Pyramidal Plane of $\{11\bar{2}1\}$. Pyramidal separation on an intersecting set of planes provides the profile at the heavy black band in the figure and registers the angle of $(1\bar{2}11)$ upon $(11\bar{2}1)$. Sample of pure antimony, superheated in purified helium to 650° C., cast, and ingot air cooled. 1000×

registering on a $\{10\bar{1}1\}$ cleavage. These, then, are the traces of the twinning planes observed previously on basal registrations.

Still other markings can be found which are not solved herein and which suggest that there might exist a more complex combination of deformational factors than is indicated in the literature. The authors are quick to confess that a rigorous solution of all markings remains to be offered. The present writing serves principally to report their occurrence.

In concluding the presentation, Fig. 7, at right, shows at high magnification the immense detail within the secondary cleavage surface — the development of pyramidal faces, the outcropping of basal weakness, and the elaborately complex path of actual fracture.

Conclusions

While these observations leave several questions unanswered, they also contain information which becomes especially evident upon referring to the previous studies on bismuth and zinc.

First, although bismuth, zinc and antimony have similar crystallographic features in that they similarly develop *(a)* basal cleavage, *(b)* secondary cleavage, and *(c)* pyramidal twinning in preference to slip, each can be readily distinguished from the other fractographically.

Second, antimony develops under conditions of deformation (as do bismuth and zinc) fractographically observable structures having the following order of formation:

1. *Twin bands*, which accommodate initial plastic movement;
2. *Secondary cleavages*, which, undoubtedly accompanied by initial basal cleavage, incept failure;
3. *Basal cleavage* (sometimes superseded by secondary cleavage), which completes the separation; and
4. *Striae*, which are believed to represent crystallographic reorientation of a microscopic surface layer experiencing a transient liquid-like condition at the moment of separation.

Third, all types and characteristics of deformation occurring in antimony can be found on the cleavage facet. These are tentatively identified as basal cleavage (and possibly slip) on (0001), secondary cleavage on the pyramidal $\{11\bar{2}1\}$ and $\{10\bar{1}1\}$ or both, and twinning on the pyramidal $\{11\bar{2}2\}$ and $\{10\bar{1}2\}$.

Fig. 7 — Secondary Cleavage on $(11\bar{2}1)$ at High Magnification, Showing the Immense Detail of the Cleavage Facet. Sample of pure antimony held at 350° C. for 12 hr. and quenched in acetone and dry ice. 3500×

In Metal Progress *last month the author described uniform attack or general corrosion, intergranular corrosion, and pitting (three of the eight forms of corrosion). In this installment of the entire discussion, two more common forms are considered and the palliatives briefly noted.*

Galvanic Corrosion and Concentration Cell Corrosion

WHEN TWO dissimilar metals are in contact with each other (or otherwise electrically connected) and exposed to a corrosive liquid or conductive solution, a potential is set up between these two metals and a current flows. Corrosion of one metal is often accelerated and the other decreased, as compared to the behavior of these metals when they are not in contact. The historic voltaic cell and the ordinary dry-cell battery are examples of such action, planned to produce current. Because of the electric currents and dissimilar metals involved, this form of corrosion is called "galvanic" or "two-metal" corrosion.

The emf. (electromotive force) series shown in Table I should be familiar to all metallurgists, chemists and chemical engineers. As far as galvanic corrosion is concerned, this series gives an indication of the potential that should exist when any two of the metals are connected. In addition, it tells us that the metal higher up in the series will suffer and the lower one will be protected. The further apart the metals in the series, the greater is the potential and the greater the likelihood of galvanic attack. For example, magnesium and copper represent a bad combination, with corrosion of magnesium greatly accelerated.

In general, the electromotive series also indicates the corrosion resistance of the elements. The metals high in the series are less resistant and more active chemically than the lower ones. The elements above hydrogen tend to oxidize readily, as shown by the fact that these elements are found in nature as oxides, sulphides, or other compounds. Those below hydrogen, such as copper, silver, and gold, often exist as metals in the natural state.

The plant man or corrosion engineer, however, usually has only academic interest in the emf. series because it is the condition of the metal or alloy *surface under actual exposure* that determines whether the material corrodes. For example, chromium occupies an unfavorable position in the emf. series, yet this element is a good metal for bright plating and is the major constituent of the stainless steels. Aluminum is near the top of the series, yet is widely used for exterior architectural trim and for the construction of domestic utensils and chemical process equipment.

The phenomenon of "passivation" is one of the reasons why metals and alloys behave differently than the positions of their elements in Table I would indicate. Passive *surfaces* on metals and alloys show more "noble" characteristics than the metals themselves — "noble" meaning better corrosion resistance. The behavior of a metal can be markedly changed because of numerous surface reactions, such as oxide formation, the presence of physically or chemically adsorbed gases, or adherent corrosion products. If one

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wishes to predict the performance of a combination of metals or alloys in contact, one should conduct tests on the actual materials in the specific corrosion environment under consideration.

A galvanic series of more practical use is also listed in Table I. This listing is based largely on tests in sea water by the International Nickel Co. The metals and alloys grouped together in the table can be used in contact with little danger of galvanic corrosion. Experience has shown that this series is of considerable value in predicting galvanic corrosion behavior in media other than sea water. This fact does not eliminate the necessity of conducting corrosion tests simulating service, particularly if unusual media or conditions are anticipated.

A number of the alloys are listed twice, once as "active" and once as "passive". Unfortunately, it is necessary to conduct tests in the corrosive environment under consideration to determine whether the materials corrode actively or show practically no attack (passivity). It results that, although quite useful for predicting galvanic behavior, the practical series presents only a general picture. For example, the alloys trade-named Chlorimet* and Hastelloy are perhaps the most universally corrosion resistant alloys (except the high-silicon irons and the precious metals).

Table I — Galvanic Series of Metals and Alloys

Electromotive Series		Practical Series; Material or Alloy
Metal	Volts	
Corroded end (anodic or least noble)		
Magnesium**	−1.55	Magnesium
		Zinc
Aluminum***	−1.33	Aluminum 2S
		Cadmium
Zinc**	−0.76	Steel or iron
		Cast iron
Chromium**	−0.56	13% Cr iron (active)
		Ni-Resist
Iron**	−0.44	18-8S (active)
		18-8S Mo (active)
Cadmium**	−0.40	Chlorimet 3
		Hastelloy C
Cobalt**	−0.29	Lead
Nickel**	−0.23	Nickel (active)
		Inconel (active)
		Hastelloy A
Tin**	−0.14	Chlorimet 2
		Hastelloy B
		Brasses
Lead**	−0.12	Copper
Hydrogen*	0.00	Bronzes
Antimony***	+0.1	Copper-nickel alloys
		Monel
Copper**	+0.34	Nickel (passive)
		Inconel (passive)
		Chromium iron (passive)
Silver**	+0.8	18-8S (passive)
		18-8S Mo (passive)
Gold***	+1.36	Silver
		Gold
		Platinum
Protected end (cathodic or most noble)		

Recognition of Galvanic Corrosion

Galvanic corrosion can often be recognized by mere visual observation. The accelerated corrosion of the less noble metal is usually localized near the points of contact and often appears as grooves or deep channels. A good example of premature failure of plant equipment because of galvanic corrosion is that of a shell and tube exchanger for heating process water (inside the tubes) by steam outside the tubes. The tubes and tube sheets were made of aluminum. Because of the length, a perforated support was placed in the center of the shell. Unfortunately, this sheet was made of steel. Examination of failed tubes showed grooves approximately ⅜ in. wide in the aluminum at points of contact with the steel. The grooves eventually penetrated the walls, and the attack was so localized that the tubes looked as if they had been machined. Condensing steam provided the electrolyte. In another instance involving air conditioning equipment, the aluminum tubes in the heater were equipped with brass fittings; the aluminum corroded rapidly in the areas adjacent to the brass.

These examples indicate that the design engineer should be particularly aware of the possibilities of galvanic corrosion, since he often specifies the detailed materials to be used in equipment. It is often economical to use dissimilar materials in contact — for example, water heaters with copper tubes and steel tube sheets. If galvanic corrosion occurs, it accelerates attack on the heavy tube sheet (instead of the thin copper tubes), and long life is obtained because of the thickness of the tube sheets. Accordingly, expensive bronze tube sheets are not required. For more severe corrosion conditions, such as acidic solutions, the bronze tube sheets would be necessary.

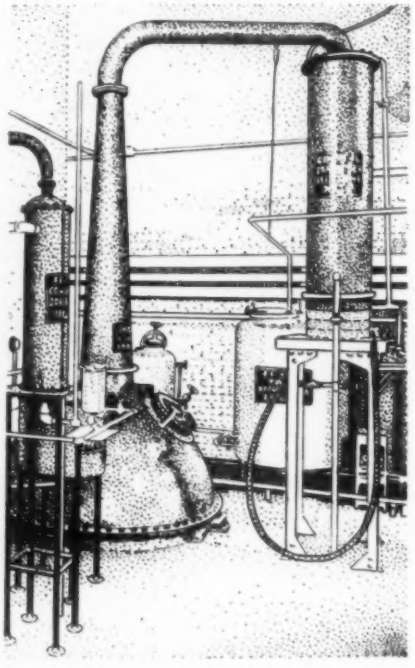
When the use of dissimilar metals is unavoidable, it is possible to minimize the effects of galvanic corrosion by several methods, as follows: *(a)* Use combinations of materials as close together as possible in the practical series; *(b)* insulate the joints (if complete insulation is not feasible, the

*Chlorimets are made by Duriron Co. and are high nickel-molybdenum alloys, some with and some without chromium. Hastelloys are made by Haynes Stellite Co. and are also basically nickel-molybdenum alloys, some with additions of tungsten, silicon, chromium or copper, alone or in combination.

use of paints or other coatings is helpful); *(c)* avoid large areas of the more noble metal, since this combination further accelerates the galvanic attack — use the reverse ratio if possible; *(d)* increase the thickness of the less noble material — for example, in fittings and tube sheets; *(e)* if paint is used for protection, paint everything, because if only the less noble material is painted, attack at pinholes or scratches in the coatings would be further accelerated because of the area-ratio effect (it may be desirable to paint only the *noble* metal — for example, steel fasteners for aluminum roofing sheet); *(f)* avoid threaded joints because the thickness is reduced by threading at points in close contact with the noble metal, and failure is likely to occur at the reduced section.

Cathodic Protection and Sacrificial Anodes

The principles of galvanic corrosion are put to practical use by methods generally designated as cathodic protection, which often prolong the life of equipment by reducing or almost completely eliminating the corrosion that would normally occur. Cathodic protection consists, briefly, of *supplying* an electric current, either external or by galvanic coupling, to a specific metal surface in such a manner that the usual electrochemical corrosion reactions are stifled or counteracted.



The methods of cathodic protection fall into two general classes — *(a)* methods using sacrificial anodes and *(b)* methods involving impressed currents or potentials. In the former, metals or alloys higher in the electromotive series than those to be protected are electrically connected or placed in contact with the equipment to be protected. In the second classification, a current is applied by means of an external source of power.

Sacrificial anodes are usually made of zinc, magnesium, and aluminum, the relatively common metals at the top of the emf. series (or alloys of these metals), depending on the nature of the equipment to be protected. Such sacrificial anodes are designed so they can be readily replaced, when necessary. In other words, cheap parts to bear the brunt of the corrosion are purposely and extraneously attached or connected to the equipment or structures involved.

Galvanized steel (steel coated with zinc) is the oldest and most familiar instance of cathodic protection. The zinc is anodic and corrodes preferentially, and thus protects the steel. Bare spots on the steel surface, formed because of mechanical damage or corrosion of the coating, are protected by the surrounding areas of remaining zinc. Household hot water tanks are protected by means of sacrificial anodes. Other examples include submarine hulls, tanker ballast tanks, and aircraft for marine service.

A more recent development is aluminized steel — steel coated with aluminum. This material was produced before the war, but normal development was retarded for the war years because of the shortage of aluminum. Aluminized steel should now find many industrial applications.

Coatings of such metals as nickel and copper on steel would produce the reverse effects and accelerate the corrosion of exposed steel. (This, of course, does not run counter to the known advantage of bimetal sheets or tubes — often of copper or nickel and steel — where each metal has considerable thickness and the equipment is designed to present a complete surface of one metal to one corrosive medium, and the other surface of the other metal to the other.) Alclad materials are other examples — as will be discussed in detail further on.

As far as chemical process equipment is concerned, perhaps the most widespread use of cathodic protection involves the protection of aluminum equipment by means of zinc strips. For example, zinc strips attached to the inside of an aluminum tank are used to protect the vessel from corrosion by the liquid handled. Sometimes the attack by the process liquor is negligible, but the cooling water on the outside of the vessel is corrosive to the aluminum; in that event the strips are attached to the outside of the vessel. Aluminum-zinc couples should be checked in the water *to be handled,* because sometimes the galvanic effects are reversed in hot waters.

Quite often a third metal is used to minimize the galvanic effects between two other metals. Figure 1 shows a zinc-aluminum-iron combina-

tion wherein zinc strips protect aluminum tubes from galvanic corrosion because of contact with a steel tube sheet in a heat exchanger. Zinc anodes cannot, of course, be used in media which chemically attack or dissolve zinc — for example, dilute mineral acids.

The spacing and positioning of the zinc or other anodic strips are important because, in general, the protection decreases as the distance from the anode is increased.

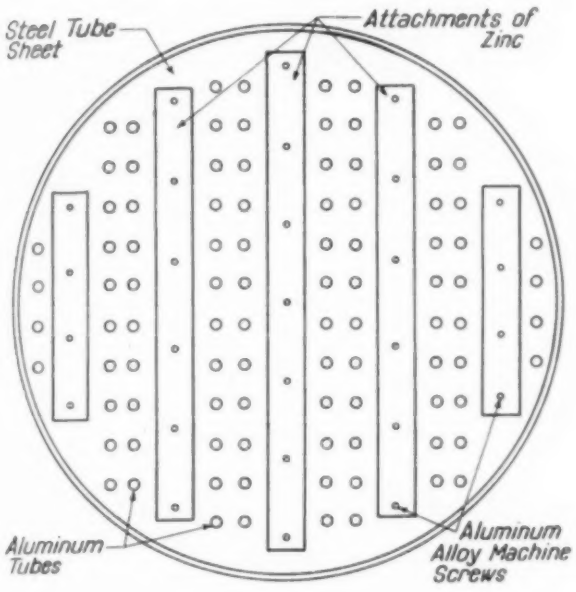


Fig. 1 — Zinc Strips Attached to Steel Tube Sheets to Protect Aluminum Tubes From Galvanic Corrosion — Zinc to Steel Replaces Aluminum to Steel (R. B. Mears and R. H. Brown)

A large amount of money is saved annually by the cathodic protection of underground pipe lines, such as the Big Inch, for transporting gas and oil across country. It might even be stated that such transport would not be economical in some sections of the country if cathodic protection methods were not utilized. Protection is mandatory, particularly in damp soil, marshes and stream crossings. Zinc, aluminum, and magnesium anodes are used. In recent years the impressed-current methods have gained in favor in spite of higher installation costs.

Alclad 3S — As an example of cathodic protection, a recent development in connection with aluminum tubing is cited which should extend the use of this material. The comparatively new Alclad 3S consists of 3S aluminum tubing with an inner lining of 72S (an aluminum-zinc alloy) which is anodic to the 3S and, accordingly, protects the 3S tubing cathodically from corrosion. These tubes were first made by drawing a 3S tube over a 72S tube (no metallic bond between the two), but they are now made with a metallurgical bond having a 72S cladding on the inside of the tubes only.

Aluminum possesses good heat transfer properties and shows good resistance to organic chemicals, waters, sulphur compounds, ammonia, concentrated nitric acid, hydrogen peroxide, boric acid, chromates, and many other common chemicals. As a result, aluminum tubing is widely used in condensers. In some, however, aluminum is pitted by water. Laboratory tests and some service experience have shown that the presence of 72S in the Alclad 3S will increase the life of aluminum tubing in corrosive water service from four to ten times.

An example will serve: In one location an Alclad 3S tube was removed after two sets of 3S tubes had failed in the same exchanger. The 72S liner showed several holes and corroded areas (about 10% had corroded away), but the 3S tubing underneath showed no appreciable attack. The bare or exposed 3S material was completely protected by the surrounding 72S. A conservative assumption would be that cathodic protection would be provided until 50% of the 72S had been removed by corrosion. On this basis the Alclad 3S tubing would show ten times the life of bare or unprotected 3S aluminum tubing in this particular service. In another case where the 72S liner (not bonded) was ripped and damaged for several inches during the rolling-in of the tubes, the 3S tubing was still protected. To date, a large amount of Alclad tubing has been installed with favorable results. Similar results have been obtained with Alclad 3S sheet in other applications.

Impressed Current

When a metal corrodes in contact with an electrolyte, many anode and cathode areas are set up; current leaves the anode (which corrodes) and enters the cathodic areas, which tend to be protected. If current from an external source is applied so that current is entering the metal over its entire area — or, in other words, if the local currents are neutralized or overcome — corrosion is minimized. This, briefly, is the principle of cathodic protection by impressed currents.

The direct-current power source could be windmill chargers, engine generator sets, or rectifiers of various types, depending upon the location of the equipment or the pipe line and other economic factors. The anodes could be made of metal or an inert material such as carbon. Available scrap iron or steel is often buried near the pipe

line and used as the external anode. Many factors, such as conductivity of the soil, spacing and location of anodes, and current densities, have to be considered in these installations, and pipe-to-soil potentials must be carefully explored.

A pipe line is a simple structure from the geometric standpoint and therefore readily amenable to protection by impressed currents. Likewise, ordinary tanks are easy to protect. For example, commercially packaged units are available and quite commonly used on water storage tanks to eliminate interior painting and also contamination of the water. These installations usually require only a small amount of maintenance and care; but simply because of their durability the maintenance men sometimes neglect to give them any care at all, with the chance that protection may be decreased or even vanish.

Complicated shapes and structures, such as are found in a distillation column, are difficult to protect because of the complex electrical arrangement required. In general, cathodic protection is not applicable where the metal or alloy involved would normally corrode at a rapid rate.

Concentration Cell Corrosion

In the section of this article just finished on galvanic or two-metal corrosion were described the cell and current flow resulting from contact of dissimilar metals. A somewhat similar situation obtains when only one metal is in contact with different concentrations in the environment. In other words, cells, current flow and potential differences exist on different areas of the same metal if this metal is in contact with different concentrations of a solution or liquid. For example, current will flow between two copper electrodes if one is placed in a solution of 5% hydrochloric acid and the other in 10% acid, the solutions being separated by porous cups. Localized attack resulting from these effects is designated concentration cell or solution cell corrosion.

Concentration cell corrosion is often associated with crevices, scale, surface deposits and other conditions where the solution in contact with the metal is stagnant. Therefore it is sometimes called crevice corrosion.

Figure 2 shows two of the most common types of concentration cells. The top portion illustrates a metal ion concentration cell and the lower an oxygen cell. In the first, iron ions build up in the stagnant area in the crevice and corner so their concentration is greater than in the liquid somewhat removed from this area. A similar condition exists in the situation indicated by the lower sketch, in that oxygen in the crevice is consumed by corrosion so that *its* concentration is lower here than in the body of the solution.

These cells cause current flow or potential differences in adjacent portions of the steel plate and destructive action occurs. The area undergoing corrosion is anodic and the surrounding area cathodic. Since the attack is localized, the corrosion is further accelerated by the large ratio of cathode to anode areas. Metal ion and oxygen cells often exist simultaneously.

The stainless steels are perhaps particularly susceptible to this form of corrosion. This is shown by failures in static solutions, often at threaded or gasketed joints. Loose gaskets often cause trouble. Incidentally, it is obvious from Fig. 2 that a butt welded joint is more desirable than a riveted lap joint, from the standpoint of concentration cell corrosion.

One reason why the rate of pitting tends to accelerate, once it is started, is the formation of

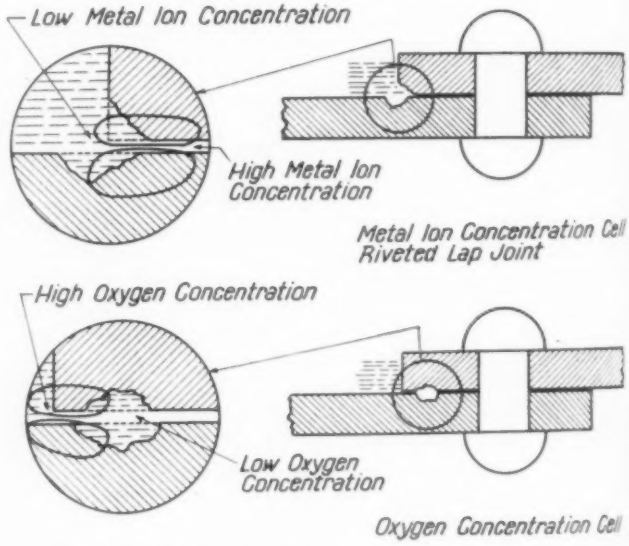


Fig. 2 — Diagrams Showing Typical Conditions for Concentration Cells (International Nickel Co.)

concentration cells between the pit and the adjacent areas of the metal. The bottom of a pit is an almost ideal site for the formation of a concentration cell.

The design engineer and the maintenance engineer familiar with concentration cell corrosion could exercise precautions, as follow, to minimize failures and excessive corrosion of this form: *(a)* Use butt welded joints with complete weld penetration. *(b)* If lap joints cannot be avoided, seal the joints by welding or caulking. *(c)* Clean and seal existing joints. *(d)* Avoid sharp corners and stagnant areas that would favor accumulation of deposits. *(e)* Clean equipment periodically.

An address delivered at Stevens Institute of Technology, Hoboken, N. J., on the occasion of the receipt of the fourth annual medal awarded by the Institute for outstanding achievement in the field of powder metallurgy.

Industrial Application of the Powder Metallurgy Process

AMERICAN INDUSTRY — primarily the automotive, farm implement and kindred industries — early manifested a keen interest in powder metallurgy. Production and design engineers were and are desirous of building into their products materials and parts that offer higher quality, longer life, greater factors of safety, fool-proof performance, mass production manufacturing methods, and over-all economies.

In the latter 1920's, and because of the apparent potentialities of powder metallurgy, much study was given the heavy duty, self-lubricating bearing. Engineers in the Chrysler organization, with which I am connected, tackled the problem and established the Amplex Division for its manufacture. The first application of so-called "Oilite" was the clutch pilot bearing, a unit that is inaccessible after assembly and located in the flange of the crankshaft. This bearing cost about 5¢, but the cost of a lubrication job on it was $3.50, and had to be repeated frequently. Oilite, the oil cushion, self-lubricating bearing provided trouble-free performance for the life of the car.

The engine water pump was a kindred problem except that here was a heavy load (because of the associated cooling fan), and a fairly high speed. Here, too, the new bearing was the answer.

From this point other automotive applications were tried. After exhaustive laboratory and road tests, oil cushion bearings were adopted for more and more parts. General industry followed a similar pattern — that is, so-called trouble jobs were tackled first. Applications followed where heavy-duty, self-lubricating bearings were the natural choice for the task.

(During this period tungsten carbide cutting tools, electrical units such as commutator brushes, breaker points — to mention but a few — were fine accomplishments, but this paper will be confined to bearings and machine parts with which the speaker is personally familiar.)

About this time, too, we wanted a bearing of greater capacity than heavy duty bronze. Research produced "Super-Oilite", the high duty, oil cushion bearing with iron-copper base. Its adaptation to production required an extensive research program of its own. Briquetting and finishing or sizing pressures were appreciably greater, sintering temperatures were higher; many variables were encountered including those of and due to the raw material. It took years and money to perfect this product. The men who were engaged in these early developments are sometimes prone to scoff at the problems put up to them today!

Machine Parts

Now regarding machine parts: As with bearings, the first machine parts were relatively small and simple in design. They were chosen for powder metallurgy because a specific property otherwise unobtainable was desired. One of the first parts we made was a gib, installed where lubrication and cleanliness were difficult to maintain.

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Thus, for a period of time, machine parts requiring a self-lubricating bearing surface were the active members.

Next came the production of machine parts involving multiple and complicated machining operations. Included were such operations as profiling and "depressing". Another group consisted of parts where the material used was unsatisfactory as to strength, wearing qualities, or both.

About this time there came a demand for larger units in both bearings and machine parts; also more complicated design for both. Bearings 3 and 4 in. in diameter were termed "very large", and the mistaken impression got around that powder metallurgy was not applicable to large units. Progress in the direction of greater size was slow because some of the materials (including those of ferrous base) needed refinement. They also required excessive pressures in briquetting and sizing operations, and there were no automatic presses available for these higher tonnages. Another impediment was the fact that presses of larger tonnages are expensive. Nevertheless, through the cooperation of bearings and parts manufacturers with the builders of press equipment, the press capacity was increased from 45 to 150, 350, 500, 1000 and more than 2000 tons.

An important factor was that of adaptability of equipment. These huge presses had to be designed and built for the production of *(a)* thrust bearings, *(b)* large diameter bearings, *(c)* large bearings and parts of appreciable length with respect to the diameter. Since it required much time to design and build these large presses, the bearings and parts manufacturer had to anticipate his requirements far ahead of actual orders.

It is because of these factors that an unusual problem presents itself with management. The management must be "powder metallurgy minded", forward looking, and willing to appropriate very considerable moneys for necessary plant and equipment. It gives me pleasure to express my appreciation to the top management of the producers of metal powders and the products made therefrom for their vision, courage and willingness to invest time and money to the furtherance of these projects.

The adaptability of oil cushion bearings and parts to mass production methods also played an early and important part in their recognition and use. It was soon established that even where subsequent machining operations were necessary such bearings and parts were definitely applicable. At first these operations were simple in nature — drilling, facing, counterboring. Later more comprehensive machining operations were added, including threading.

Friction members for clutches and brakes, and filters for liquids and gases have made good progress. Advantages of powder metallurgy are manifold: For clutches and brakes these advantages include compactness, longer life, heat dissipation, and a selection of coefficients of friction and wear factors. Filters are sturdy, calibrated, economical, applicable to liquids and gases, and highly noncorrosive.

Making the Hard-to-Make Parts

During the grim period of the early 1940's, many contributions were made by the fabricators of parts from powder metals to the needs of the armed forces. One very important fact was emphatically established — their ability to tool-up and get into production very quickly, not only on simple parts, but others of more complex nature.

There comes to my mind such designs as an external spline on a flange unit where the spline ran at full depth to the face of the flange. Other parts had depressed areas, still others had eccentric bores, and holes or depressions square, hexagonal, or rectangular in shape. It is, of course, difficult and expensive to machine accurately a rectangular bore ⅛ in. wide and ¾ in. long into a boss on a machine part. Operations such as these are what we term "naturals", readily performed through powder metallurgy techniques. With the wartime demand for tremendous quantities of peculiar parts, tooling programs for normal machining operations stretched out into many months. However, it was not unusual to be in production on a complex part of powder metal within six weeks, as compared to an 18-month delivery promise on machinery and tools for conventional machine-shop methods. Strategic metals, too, were conserved through substitution of ferrous powder for copper and tin, and further savings were provided through the elimination of chips and scrap.

At a recent ordnance meeting in Detroit an Army general stressed the fact that with the exception of a very few items, equipment used in World War II is already obsolete! Now, what are the basic requirements of new and ultramodern equipment? They include high velocity, materials that will withstand higher temperatures, and decreased weight. That last consideration — weight — is highly important. It is frequently overlooked that parts and bearings made of powder metals are light weight in material, due, of course, to their controlled porosity. Gentlemen, I believe you will agree with me that many objectives of modern equipment can be accomplished through powder metallurgy based upon research.

The Chrysler Corp. is no exception to other great companies in their philosophy concerning research and development. In our Powder Metal Division we have been dedicated to a far-reaching research program from the very beginning, and we have the advantage of coordinating with the main Chrysler laboratories having specialized personnel in several allied fields. In our opinion, this philosophy is basic for the success of American enterprise, if it is to provide an ever higher plane of living, and be able to contribute to national preparedness and safety.

It is sometimes a difficult matter to tool-up and get into production on the parts and equipment that we know how to make. However, it is infinitely more difficult to accomplish this when we don't know how to go about it. Obviously, such accomplishments can only be achieved through research and coordinated effort executed long before the necessity arises for delivery.

In the over-all picture there are many favorable factors for products of this branch of powder metallurgy. One is the ready application of mass production principles. Another is the fact that first-rate powder metallurgy products are homogeneous, chemically and physically. The process eliminates scrap and expense because it side-steps defects such as blowholes, hard spots and similar difficulties in rough castings or forgings that often do not appear until the final machining operations. Bearings of powder metals have decreased clearances, making for longer life, assemblies of greater precision, and quiet operations.

Unequalled, too, in any other product is the facility for sizing an oil cushion bearing during or after assembly. Modern mechanization requires higher factors of safety and more foolproof operations. What a boon it is to have a bearing functioning perfectly with little or no attention, as compared to a unit that needs to be lubricated every day. What an advantage to have trouble-free operation on a bearing that may one day be operating in the Sahara Desert, while its twin brother functions in the frozen north of Iceland!

Tooling Problems

Busy days for designing engineers, manufacturing, tooling, and purchasing personnel are always intensified when new models are being introduced. Machinery, factory equipment, jigs, fixtures, and cutting tools — all must be provided as part of the program. The next thing is to get delivery and put them into production. By contrast, what an advantage to merely submit a blueprint to the manufacturer of metal powder machine parts and receive those parts ready for assembly, without increasing capital investment, or incurring the expense and travail of putting a unit into production.

Furthermore, tooling programs of today are far more expensive than at any time in history. Powder metallurgy can be of great assistance in effecting economies, and expediting deliveries to corporations engaged in bringing out revised or new designs. Moreover, materials and techniques have been improved, resulting in machine parts of attractive physical properties.

Interesting is the fact that in Chrysler Corp. products we are now using 91 Oilite bearings or machine parts. We know that we have a long way to go before we reach the saturation point in our products. To accomplish our objectives, highly specialized equipment has been provided. The not-too-distant future may bring us into the field where single-purpose equipment may be installed in powder metal manufacture, as is common in other mass production operations.

Future Improvements Needed

Let us now consider the raw materials, the metal powders. The field of such manufacture has broadened appreciably, particularly for iron powders. Moreover, new processes are in production, and older ones have and are undergoing changes. A number of other processes still in the development state appear promising indeed. In the ferrous field, a number of lower priced iron powders are available. However, my belief is that there is a definite need for what might be called ideal powders, particularly for special applications.

From my background as a toolmaker, I see one goal as this — metal powders so constant and uniform that a briquetting press may be set up with as much speed and continuity as is usual in setting up automatic machine tools. Moreover, it seems probable that a continuous research program through coordinated effort would promise the attainment of this goal.

What is the forward picture for this branch of powder metallurgy? I cannot feel other than sanguine about the future. Plenty is yet to be accomplished in the field of both bearings and machine parts. Since our products are ferrous and nonferrous, we can get an idea by comparing this country's annual tonnage of copper with that of iron and steel, because in powder metallurgy our tonnage ratios are now in the reverse order. Beyond that, new materials, new alloys, specialized processing by bearing and parts manufacturers, greatly improved physical properties, larger and heavier briquetting and sizing presses are our objectives. I know they will be realized.

The 1948 A.I.M.E. Meeting

THE STEADY TREND of ferrous and nonferrous metallurgy toward a common ground was hastened noticeably by the technical papers presented at the 1948 meeting of the American Institute of Mining and Metallurgical Engineers, held in New York City in February. This sharing of problems by the ferrous and nonferrous metallurgists was in harmony with recent discussions by the Institute's management concerning the possibility of future amalgamation of the two metals divisions. Joint meetings are a boon to the earnest seeker of knowledge, frequently puzzled to choose, from the scanty information on the printed program, between simultaneous meetings. So large have become the demands that the facilities of the Engineering Societies Building, where the annual meetings have been held for so many years, have been outgrown, and this year no less than 24 meeting rooms in the Hotel Pennsylvania were listed in the program!

Outstanding in the metallurgical meetings were four joint sessions of the Institute of [Nonferrous] Metals Division and the Iron and Steel Division. Here theoretical physical metallurgy was discussed without regard for any superficial differences between ferrous and nonferrous metals. Two of these joint sessions dealt broadly with kinetics; particular problems were diffusion, grain growth, precipitation, anelasticity, and transformation in the solid state.

Transformation in Cobalt, Lithium and Steel

New data on cobalt (A. R. Troiano and J. L. Tokich) and lithium (C. S. Barrett and O. R. Trautz) prompt the conclusion that these metals are more like certain iron-base alloys in transformation characteristics than is iron itself! Both cobalt and lithium transform at low temperatures in much the same way that steel transforms to martensite during cooling or deformation. In fact, "martensite" has been used as a general term to describe all transformations of this type—for example, in the article by A. R. Troiano and A. B. Greninger in *Metal Progress* for August 1946.

The above-mentioned paper by Troiano and Tokich (University of Notre Dame) should clear away much old confusion concerning the transformation of cobalt, but there are some new complexities. For instance, decreasing the grain size made it possible for the experimenters to stabilize the high-temperature form of cobalt at room temperature. This raises the interesting question whether, for some range of fine grain size in steel, the transformation of austenite to martensite would be similarly affected.

The paper by C. S. Barrett and O. R. Trautz (University of Chicago) described transformations in lithium below room temperature—in fact, below the boiling point of nitrogen (−320° F.). Under certain conditions, the transformation is noisy, accompanied by audible clicks which are similar to the sound given off by tin when it is being deformed. The noisy transformation was also studied in lithium-magnesium alloys containing up to 85% magnesium. The authors pointed out the similarities between the transformation of lithium and that of austenite to martensite. Here, as with cobalt, certain of the results inspire new experiments on steel. For instance, the cold working of lithium above M_s stabilizes the metal against transformation during

Reported by
Taylor Lyman
Editor, Metals Handbook

subsequent cooling. Would an analogous effect be observed with steel?

A further refinement in the technique for determining the amount of retained austenite in steel was presented by B. L. Averbach and Morris Cohen (Massachusetts Institute of Technology). The new method, directly applicable only to steel in the as-hardened condition, depends on measurements of the integrated X-ray intensities and does not require external calibration or a standard reference foil.

End-Quench Tests on Aluminum Alloys

Although there were no papers concerning the hardenability of steel, the Jominy specimen entered the discussion in other ways. The familiar end-quench test has now been used in the study of mass effect in the heat treatment of age-hardening aluminum alloys, and also in the evaluation of quenching oils.

B. M. Loring, W. H. Baer and G. M. Carlton (Naval Research Laboratory) end quenched modified L-type Jominy specimens in order to evaluate critical rates of quenching (before aging) for 14S, 24S, 61S, 75S and R301. The quenching rate is important when these aluminum alloys are to be heat treated in heavy sections. Only in 75S was there an appreciable variation of hardness along the Jominy bar after the end-quenched specimens had been reheated properly for precipitation hardening. For 75S this variation was from Rockwell B-89 at the quenched end to B-71 at the 3½-in. position.

C. A. Siebert and G. Sandoz (University of Michigan) reversed the usual purpose of the Jominy test and, with a given steel (9450), varied the quenching medium in order to evaluate the cooling power of five different oils. It was found that with high rates of agitation, such as those inherent in the Jominy test, there is little, if any, advantage to be gained by using any of the three proprietary compounded oils they tested in place of a straight mineral oil.

Phase Diagrams

A session on phase diagrams was of interest mostly to nonferrous metallurgists — iron got into the discussion only to the extent of its slight solubility in magnesium. The systems discussed were aluminum-sodium, copper-aluminum-silicon, copper-nickel-chromium and magnesium-iron.

The report on aluminum-sodium alloys by W. L. Fink, L. A. Willey and H. C. Stumpf (Aluminum Co. of America) was the 21st in a series from the Aluminum Research Laboratories describing equilibrium relations in aluminum alloy systems. Sodium lowers the melting point of aluminum by 1.2° C.; the eutectic point is at 0.18% Na and 659.0° C. (1218.2° F.).

Copper-aluminum-silicon alloys containing up to 8½% Al and 3½% Si were investigated by F. H. Wilson (The American Brass Co.). The most conspicuous feature of this important ternary system is the existence of the kappa phase of the copper-silicon binary alloys at the highest aluminum content investigated.

W. R. Hibbard and co-workers (Yale University) studied the copper-nickel-chromium system, chiefly to determine the effect of chromium on copper-base alloys containing 10, 20 and 30% nickel. Chromium makes cupro-nickel age hardenable. The maximum hardness of the ternary alloys is about the same as in the binary copper-chromium alloys.

A small content of iron markedly increases the rate of corrosion of magnesium, and for this reason commercial specifications for wrought magnesium alloys limit the iron content to 0.005% max. Consequently the paper by D. W. Mitchell (University of California) on the solubility of iron in liquid magnesium was of practical as well as academic interest. He reported that the magnesium end of the binary system is simple eutectic with a eutectic composition of about 0.031% iron. The solubility of iron increases to 0.26% at 1000° C. (1830° F.).

An A.I.M.E. meeting would not be complete unless there were discussions about the mechanism of plastic deformation of nonferrous metals. This year these contributions provided a full session of five papers, with four similar contributions being presented as part of the joint session on theoretical physical metallurgy. New data by P. A. Beck, John Towers, Jr., and W. D. Manly (University of Notre Dame) showed that, as in pure aluminum, isothermal grain growth in 70-30 brass can be described adequately by an equation of the form $D = Kt^n$.

Powder Metallurgy

Powder metallurgists have never emphasized the differences between ferrous and nonferrous metals, so it is perhaps not too surprising that the Institute of Metals Division should sponsor a series of papers dealing almost entirely with iron and steel powders. Unfortunately they occurred on a day when other interesting subjects competed for audiences. Likewise Stevens Institute of Technology, over the river in Hoboken, staged an evening meeting when A. J. Langhammer of Chrysler Corp. was given a medal for his long services to

the powder metal industry. His acceptance address is reproduced in this issue (p. 387).

Powder compacts always contain holes, which are sometimes used to good advantage, as in bearings and filters. Pol Duwez and H. E. Martens (California Institute of Technology) discussed the powder metallurgy of porous alloys for a relatively new use.

In the cooling system of a jet engine the metallic part which had to be kept cool was made of a porous alloy, so that the cooling fluid could be forced through the pores, counter to the direction of heat flow. This method, referred to as "sweat cooling", requires a material of controlled permeability. Since the tensile strength of a porous alloy decreases with increasing porosity, it is important to develop porous alloys having maximum permeability with minimum porosity.

The method of Duwez and Martens mixes ammonium bicarbonate with the metal powder, presses the mixture, heats it to dissociate the ammonium bicarbonate and to create the desired porosity, and then sinters the compact. A single relationship exists between the permeability and the amount of ammonium bicarbonate used in preparing the porous alloy. The materials investigated were 18-8 stainless steel prepared from a pre-alloyed powder, and nickel-molybdenum-iron alloy (65% Ni, 30% Mo, 5% Fe) prepared from a mixture of powders of the pure metals. The properties of the pressed and sintered materials were reported as functions of the porosity.

Tests and Interpretations

It is unusual when a paper interests both the Iron and Steel Division and the Milling Methods Committee of the A.I.M.E. The paper "Wear Tests on Grinding Balls" by T. E. Norman and C. M. Loeb, Jr. (Climax Molybdenum Company) was such a one, and appeared on the programs of both groups. It was reported that, in steel grinding balls, a matrix of martensite or low-temperature bainite, plus retained austenite, showed the best resistance to wear. Spheroidized carbides increased the wear resistance of a martensitic matrix. Methods of identifying the marked balls under test, as well as a similar number of "standard" balls, after a week's run in a grinding mill, and establishing an order of merit for the different types of ball in each charge were interestingly described by the Editor of *Metal Progress* in his "Critical Points" for July 1941.

It is impressive to consider the diversity of electrical equipments that are coming to bear on problems of metallurgical research. For instance, the investigator now mentions the use of Geiger counters, microphotometers and oscilloscopes in close juxtaposition with the more familiar metallurgical equipments like pyrometers, dilatometers and lever systems. No doubt, many mechanical zombies are due to be pushed entirely out of the metallurgical laboratory by some of the newer electrical instruments.

Another notable — and somewhat fearsome — trend is toward the use of unfamiliar mathematics (page Michael Corson!). So far, this tendency seems confined mostly to discussions of kinetics — especially diffusion. Five papers in the joint sessions on theoretical physical metallurgy were chiefly mathematical in argument.

Lectures and Awards

In contrast with the stern mathematics of diffusion was the annual lecture of the Institute of Metals Division, by Cyril Stanley Smith, director of the Institute for the Study of Metals of the University of Chicago. Dr. Smith, speaking on the subject "Grains, Phases and Interfaces: An Explanation of Microstructure", showed that there is much to be learned of microstructure simply by taking clearer and deeper thought of what can be seen of metals under the ordinary metallurgical microscope. Using a few familiar examples, both ferrous and nonferrous, the lecturer pointed out many fresh and significant aspects of microstructure, aspects that might easily be overlooked by an observer not inclined to look long and searchingly at his specimens. He mentioned especially the influence of surface tension between and among metal crystals on the characteristic micro-appearance of single-phase and duplex alloys. Small grains, large grains, round grains, flat grains, inclusions, segregates, twins and dendrites all depend on surface tensions.

What a pity there are no lectures in metallurgy at the University of Chicago; Cyril Smith would inspire any student to a keen appreciation of microstructure.

The 25th Howe Lecture was presented by Robert B. Sosman, Professor of Ceramics, Rutgers University. His subject was "Temperatures in the Openhearth Furnace".

The Robert W. Hunt medal was awarded to B. M. Larsen and T. E. Brower (United States Steel Corp. Research Laboratory) for their recent papers on oxygen in liquid openhearth steel.

The Alfred Noble prize of the Founder Engineering Societies and the Western Society of Engineers was given to John H. Hollomon (formerly of Watertown Arsenal but now with General Electric's metallurgical research) for his paper entitled "The Mechanical Equation of State".

Revised...

AT YOUR FINGERTIPS

Standard Designations and Chemical Composition Ranges for Heat and Corrosion Resistant Castings have been revised by the Alloy Casting Institute. The chart below puts all this data conveniently

DESIGNATION	Co... —							
	C	Mn max.	Si	P max.	S ma...	...	Ni	Other Elements
CA-15	0.15 max.	1.00	1.50	0.04	0.04	...4	1 max.	Mo 0.5 max.†
CA-40	0.20-0.40	1.00	1.50	0.04	0.04	1....	1 max.	Mo 0.5 max.†
CB-30	0.30 max.	1.00	1.00	0.04	0.04	18-2...	... max.	—
CC-50	0.50 max.	1.00	1.00	0.04	0.04	26-30	1 m...	—
CE-30	0.30 max.	1.50	2.00	0.04	0.04	26-30	...	—
CF-8	0.08 max.	1.50	2.00	0.04	0.04	18-21	8-11	—
CF-20	0.20 max.	1.50	2.00	0.04	0.04	18-21	8-11	—
CF-8M	0.08 max.	1.50	1.50	0.04	0.04	18-21	9-12	Mo 2.0-3.0
CF-12M	0.12 max.	1.50	1.50	0.04	0.04	18-21	9-12	Mo 2.0-3.0
CF-8C	0.08 max.	1.50	2.00	0.04	0.04	18-21	9-12	Cb 8xC min., 1.0 max.
CF-16F	0.16 max.	1.50	2.00	0.17	0.04	18-21	9-12	Mo 1.5 max., Se 0.20-0.35
CF-16Fa	0.16 max.	1.50	2.00	0.04	0.20-0.40	18-21	9-12	Mo 0.40-0.80
					...04	20-23	10-13	—
					...04	22-26	12-15	—
					...04	22-26	12-15	—
					...04	23-27	19-22	—
					...04	26-30	4 max.	Mo 0.5 max.†
					...04	26-30	4-7	Mo 0.5 max.†
					...04	26-30	8-11	Mo 0.5 max.†
					...04	18-23	8-12	Mo 0.5 max.†
					...04	24-28	11-14	Mo 0.5 max.† N 0.2 max.
					...04	26-30	14-18	Mo 0.5 max.†
					...04	24-28	18-22	Mo 0.5 max.†
HU	0.35-0.75	2.00	2.50	0.04	0....			
HW	0.35-0.75	2.00	2.50	0.04	0....			
HX	0.35-0.75	...00	2.50	0.04	0....			

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It provides concise data to help you select alloy castings for use under conditions of elevated temperature, severe corrosion, or both. Use the chart when ordering or specifying Nickel-Chromium-Iron alloy castings. Copies are available on request . . . mail the coupon now.

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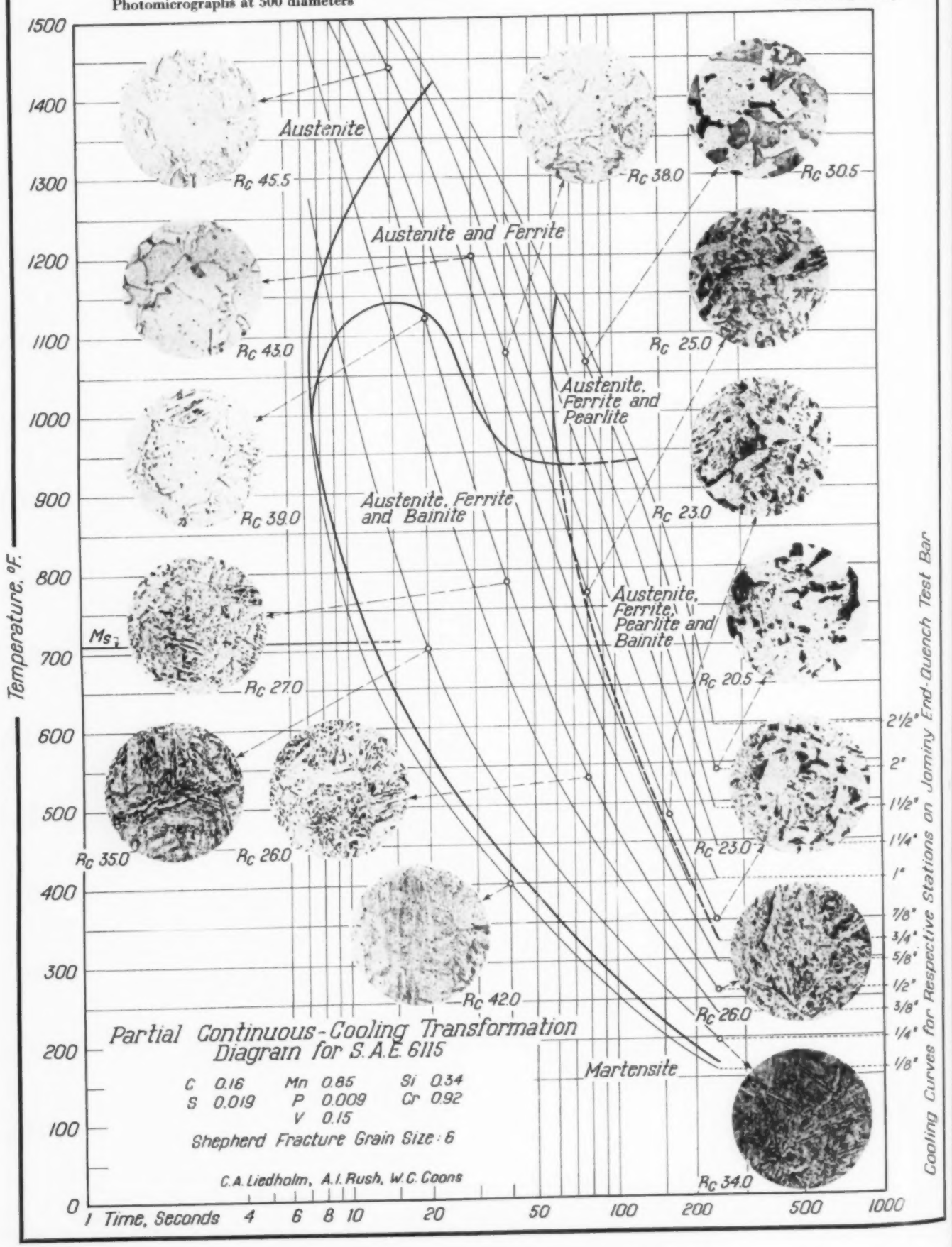
THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N.Y.

Transformation of S.A.E. 6115 Steel

During Continuous Cooling

By C. A. Liedholm
A. I. Rush
and W. C. Coons
Curtiss-Wright Corp.

Photomicrographs at 500 diameters



The author, who has discussed today's heat treating furnaces before several chapters in past years, has summarized information on modern practice in bright annealing of the heavy nonferrous metals and alloys, with some notes on recent practice in the precious metal industry.

Atmospheres and Controlled Atmosphere Furnaces for Nonferrous Metals

WITH ONE IMPORTANT EXCEPTION* the use of controlled atmospheres in the treatment of nonferrous metals is for a primary purpose only — namely, for preserving or improving the appearance of the surface of the work during the annealing process. The furnaces, therefore, usually differ in application from those used for steels; in the latter not only is the control of surface appearance and condition involved, but more frequently the control of carbon content is of equal, or even greater, importance. The single-purpose use of annealing furnaces in the nonferrous industry is thus conceivably a main reason why so little has been disclosed about the atmospheres and types of furnace equipment. Yet the equipment comprises a large percentage of all furnaces having controlled atmospheres, and in many instances the problems introduced are by no means easily solved. Being void of any such alloying element as carbon, rather than simplifying the metal's treatment, often introduces complexities which require more careful consideration than when this element is present.

Although the bright heat treatment of ferrous metals does not permit radical variations, many nonferrous metals can be annealed to the same degree of brightness in totally different types of furnaces. A consideration of the required atmosphere discloses why this is true. Some of the nonferrous metals, such as copper, nickel and many of their alloys, are comparatively easy to keep bright. They are oxidized by free oxygen only. Carbon dioxide and water vapor are inert to these metals. Prior to the present-day gas generators, steam was the universal atmosphere for bright annealing copper. Even today steam is used in some modern batch-type furnaces during the first part of the heating cycle.

Carbon monoxide, hydrogen and hydrocarbons are the reducing constituents of the gas. Their presence is always necessary in the protective atmosphere, for they assure not only the complete elimination of all free oxygen during combustion of a suitable air-gas mixture, both in the atmosphere preparation unit and in the direct-fired bright annealing furnace, but also counterbalance traces of oxygen which may enter the furnace. Furthermore, they reduce any oxides already on the surface of the work.

The required percentage of reducing constituents is largely dependent upon metal to be heat treated. Copper and nickel are bright annealed in

*Namely, heat treatment of the light metals.

By William Lehrer
Research and Development Engineer
Surface Combustion Corp.
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atmospheres containing as low as 1.5% of reducing gases. Such so-called "lean" atmospheres prevent absorption of hydrogen from the hot atmosphere — "hydrogen embrittlement" of electrolytic copper — and also staining of the work due to traces of hydrogen sulphide. (Many raw fuel gases, particularly coke oven gas, contain sulphur compounds. By adjusting the air-gas ratio to a slight deficiency of air, most of this is oxidized during combustion to inert sulphur dioxide, and the hydrogen sulphide is thus reduced to a minimum.)

"Rich" atmospheres of approximately the same composition as utilized for bright annealing steel are used extensively in the heat treatment of precious metals. Even though some of these — like pure silver, gold, and palladium — are protected by only a small percentage of reducing gases in the atmosphere, a large number of noble metal alloys must be bright annealed in highly reducing atmospheres.

The above statements concerning the inertness of water vapor to some nonferrous metals do not apply to precious metals. The permissible moisture content or dew point is contingent upon several factors. The dew point is, first of all, governed by the composition of the atmosphere; the higher the hydrogen content, the higher can be the dew point, for tests have proven that a definite $H_2:H_2O$ ratio is required for each truly bright annealing atmosphere for precious metals.

The allowable dew point also depends upon the annealing temperature and particularly upon the rate of cooling the metal from its maximum temperature. In this respect the precious metals behave similarly to steel. There is a critical temperature range in which they are most susceptible to oxidation by water vapor. Above this temperature, progressively larger concentrations of water vapor can be tolerated because of the increased reducing power of hydrogen at the higher temperature. Below the critical temperature, the rate of oxidation by water vapor gradually diminishes until it becomes negligible at room temperature. Extremely fast cooling rates, such as are obtained by quenching in water, therefore permit much higher dew points in the bright annealing furnace atmosphere than when the work is slowly cooled. These considerations explain why some furnaces turn out oxidized work with the same atmosphere which produces perfectly bright work in others.

The type of metal largely determines the quality and the dew point of the atmosphere for bright annealing. Gold, fine silver and palladium can, like copper and nickel, stand a high dew point. Alloys containing zinc, on the other hand, are much harder to keep bright, and the problem becomes increasingly difficult the higher the zinc content. Zinc, when heated, oxidizes readily in air, but it also is oxidized by hot CO_2 and H_2O. A suitable atmosphere for brass or other zinc-bearing alloys must, therefore, exclude these gases. This requires the use of either an inert gas, such as nitrogen, or an actively reducing gas, such as hydrogen or hydrogen-generating constituents like decomposition products of methanol or other hydrocarbons. Both are rather expensive, so in mass production such metals are annealed to produce a slight oxidation which is easily removed by flash pickling. The resulting surface is commonly referred to as "clean annealed".

These greater difficulties in bright annealing apply to the tons of copper-zinc alloys produced in the copper and brass mills, as well as to the pennyweights and ounces of zinc-containing alloys in the precious metal industry. Twenty-four karat gold, for instance, is just as readily bright annealed as copper. The lower karat red, yellow, pink,

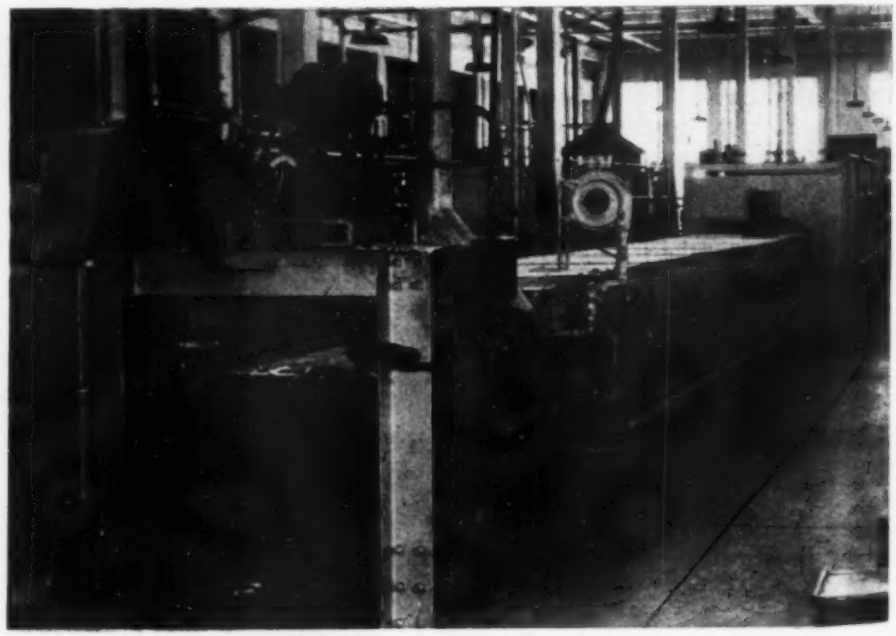

Fig. 1 — Discharge End of Continuous Bright Annealing Furnace for Sterling Silver. Flat ware is carried through muffle and long chamber for slow cooling on woven chain belt

green, and white golds, however, are considerably more troublesome, because their zinc content runs progressively higher (as much as 18%).

The toughest metals to bright anneal in the precious metal field are the so-called "nickel-silvers" — alloys with 60 to 65% copper, the balance being nickel and zinc in various proportions. Here, again, the high-nickel alloys present less trouble than the low. The real "bearcat" is the "10% nickel-silver", since it contains from 25 to 30% zinc. Any atmosphere composition and dew point which bright anneals the "10% nickel-silver" will therefore be suitable for the other alloys. (Figures 1 and 2.)

Still lower dew points are necessary for bright annealing those nonferrous metals which contain silicon. Silicon has a very great affinity for oxygen, free or combined, when hot. The resultant oxidation forms SiO_2, the refractory silica, which cannot be removed from the surface by ordinary pickling. Silicon-brass, combining the difficulties due to silicon and a high-zinc content, requires a practically bone-dry atmosphere for bright annealing.

In general, carbon dioxide behaves very similarly to water vapor. As with the H_2:H_2O combination, it is the CO:CO_2 ratio, rather than the CO_2 percentage alone, which determines the concentration permissible for bright annealing. Its action on nonferrous metals is less severe than that of water vapor. Nevertheless, its presence is a warning signal since it combines with hydrogen and produces water vapor until the fourfold equilibrium of CO_2:CO:H_2O:H_2 is reached, thus raising the dew point of an initially dry atmosphere within a hot furnace. Carbon dioxide must, therefore, be completely removed from all bright annealing gases which are dehydrated in the gas generator and which must remain dry in the furnace. Such precautions are particularly desirable for the "nickel-silvers" and necessary for silicon-brass alloys.

The Light Metals

The complete omission of any mention of aluminum, magnesium and their alloys up to this point has been deliberate. These two rapidly-growing additions to the nonferrous family belong in a class by themselves. For, contrary to the objective in the heavy nonferrous industry, heat treatment of the light metals and their alloys in controlled atmospheres involves not so much the surface appearance as the effect of the atmosphere on the properties of these metals. Deterioration in the physical properties due to oxidation by certain gas constituents is accompanied by a change of the surface, such as blistering. Aluminum and magnesium alloys are unique also in that they are oxidized by gases which are inert to most of the other nonferrous metals, and are unaffected by gases which oxidize copper alloys. Free oxygen seems quite harmless in the heat treatment of aluminum and magnesium. Air, with or without slight additions of other gases, is therefore the preferred and most common atmosphere.

Sulphur dioxide is inert to magnesium alloys (as it is to copper, nickel and silver), and additions to a concentration of a few tenths of one per cent are generally considered best for magnesium, both to prevent minor surface oxidation and major burning. Yet this same SO_2 gas, in even very small percentages, is extremely injurious to aluminum and its alloys.

Even though the general behavior of the aluminum and magnesium alloys in controlled atmospheres differs greatly from the heavy nonferrous metals, there are two points of similarity: Water vapor beyond a certain concentration is as detrimental to aluminum as it is to precious metals. The second point regards the metal's composition: Progressively higher silicon content leads to universally greater difficulties in selecting and applying suitable atmospheres.

A survey of the available literature discloses the unfortunate fact that, whereas the controlled atmospheres for the predominant heavy nonferrous metals and their action during heat treatment are known quite definitely and completely, there is relatively little corresponding information about aluminum and magnesium alloys. This condition has unquestionably been brought about by the rapid development of these alloys during the war. It is hoped that the quieter peace years will soon produce the desired data. For this reason no discussion of furnaces, particularly designed for aluminum and magnesium, is given in this article.

Principles of Furnace Design

From the preceding discussion of atmospheres, it is apparent, though not surprising, that their diversity is to be attributed to the *variety* of metals and alloys to be heat treated. A similar diversity is found also in the types of furnaces.

Broadly, a controlled-atmosphere furnace includes a heating and a cooling chamber in which the work is surrounded by and in contact with gases of a fixed composition. According to this generally accepted description, it is a furnace in which the heating gases and the protective gases are separated, either by means of a muffle or by burning the heating gas in radiant tubes. But if the heating gases, after combustion, reach a com-

position suitable for the desired protection of the work, the direct-fired furnace becomes a controlled-atmosphere furnace. Such is the case in the bright annealing of copper, nickel, silver and many of their alloys. Since the CO_2 and H_2O which are formed in the combustion of commercial fuel gases do not oxidize these metals, the burners of the direct-fired furnace are the common source of heat and atmosphere. It is necessary only to set the air-gas mixture slightly on the reducing side to safeguard against the presence of any harmful free oxygen in the products of combustion.

Present-day proportioning devices are of sufficient accuracy to assure a constant flue-gas analysis over the entire range of burner capacities and turndown. Thus, the same composition of the gases within the furnace chamber is maintained regardless of the rate of firing.

Heating Methods — The direct-fired furnace is obviously most economical in operating cost and low in initial capital investment; it is therefore preferred whenever possible. A large percentage of the bright annealing of copper is done in direct-fired furnaces. The heating elements either consist of several burners of small capacity arranged to fire above and below the work and from both sides, or comprise one or two heaters placed outside the work-heating chamber and in the path of an external fan which recirculates large volumes of hot gases through the furnace. This is known as "convection heating"; it is particularly well suited for nonferrous metals because of their comparatively low annealing ranges, wherein transfer of heat by convection is much more efficient than by radiation.

Such furnaces promote uniform and rapid heating, and may be readily protected by combustion safety devices. They also have the advantage of greatly simplifying one of the most important problems — namely, leakage into the furnace. It is needless to point out the value of a gas-tight construction which prevents contamination of the furnace atmosphere by air infiltration. It is equally essential to prevent air infiltration at the doors. A constant, safe minimum flow of atmosphere which always builds up a slight positive pressure within the furnace chamber is an essential.

In a muffle or radiant tube furnace, this constant atmosphere flow is supplied by a gas generator of suitable capacity. In direct-fired furnaces the problem is complicated by the fact that the burners, which are the source of atmosphere supply, must fire at varying rates in order to hold the heating zone at the desired control temperature. In the convection-type furnace the problem is readily solved by firing the burners at a constant rate or within safe close limits, and providing a cooling coil or a cooling tower in the return ducts through which a portion of the gases is bypassed by a damper operated by the temperature control. This throws a constant load on the burners, and the rate at which the atmosphere flows into the furnace is maintained constant without sacrificing accuracy and uniformity of temperature control.

Obviously, this method is not adaptable to open-fired furnaces heated by burners distributed

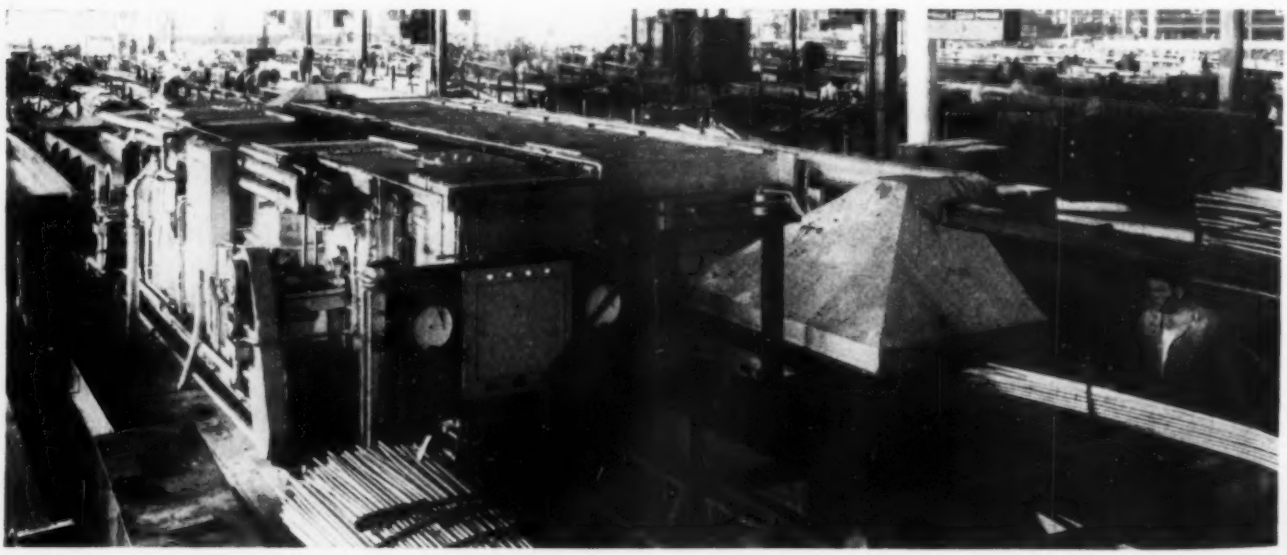

Fig. 2 — Convection Heated Bright Annealing Furnace for Copper Tubes. Continuous furnace with roller hearth. Because of limited head room the heater boxes and recirculating fans are placed alongside the work-heating chamber

along the heating zone. The minimum heat demand is often such that enough products of combustion are supplied to prevent air infiltration at the work openings. Then, when the burners fire at full rate, an excess of gas volume is produced which issues from the doors at an increased velocity. However, if the doors are too large or the minimum burner demand too low it then becomes necessary to resort to a "make-up" atmosphere such as steam. Additional atmosphere volume is automatically produced when a direct water spray cools the work to below tarnishing temperature before it is discharged into the air.

Atmosphere volume requirements are reduced to a minimum by special sealing devices at the work openings. Flame screens, asbestos or fireproof cloth curtains, eductors, heat seals, and manually or automatically operated doors are most commonly employed. Choice is governed by the type of conveyer most suitable for the particular work to be handled, by the cycle of furnace operation, by the height of the required work openings, and by the shape and size of the work itself. Atmosphere requirements are higher in continuous furnaces than in batch-type; the latter require sufficient flow only for initial purging and for replenishing loss through seals and at bleeders, if such are employed.

Cooling methods in considerable variety are found. No matter how perfect the quality of atmosphere, the work will not come out bright unless it is cooled in the protective atmosphere to below tarnishing temperature — usually 200° F. or below. (Normally, it is as low as 150° F. for easier handling of work from the run-out table.) Other factors, such as delayed discoloration, also affect the temperature to which the work is cooled within the furnace.

Being void of any hardening element like carbon in steel, the physical properties of most nonferrous metals are not changed by the *rate* of cooling. For practical purposes, the softness of the annealed metal remains the same whether it is cooled slowly or water quenched or sprayed. Since floor space and initial investment are two important considerations, the relatively short chamber for a water quench is selected whenever some water staining of the work is permissible. (This applies to practically all process annealing and also to some finish annealing operations.) The work may be cooled by immersion, spray, or fog quenching. Water is the universal quenching medium. To eliminate as much of the free water as possible from the surface of the work, hot quenching water is frequently used. The usual discharge temperature (150 to 200° F.) promotes rapid evaporation, as long as sufficient surface is exposed. Some classes of work, like coils, cannot be water quenched because water works in between the wraps of the coil causing water staining.

All work requiring a high quality of surface brightness must be cooled in a comparatively dry protective atmosphere. This considerably increases the cooling time and necessitates long cooling zones. In direct-fired furnaces the high content of water vapor in the heating atmosphere is reduced to the low percentage necessary in the slow cooling zone by dehydrating the gases in a gas-recirculating section provided with a cooling coil and inserted between the heating and the cooling chambers. In indirect-fired furnaces the moisture content of the atmosphere for both heating and cooling zone is lowered to the desired dew point in the gas generator. The slow-cooling zone, which is normally 2½ to 3 times the length of the heating zone, can be shortened appreciably by apply-

Fig. 3 — Furnace for Bright Annealing of Copper Tubing. At the extreme right edge of picture are stock racks and entry table. Next toward the left is the heating section of the furnace, then a cooling zone with a lower roof ending with a spray quench (water tank below), and finally there is a run-out table of appropriate length

ing forced convection cooling. Proper design has created fast-cooling zones which are only a fraction longer than the heating zone.

Some cooling chambers incorporate both slow cooling and water quenching (see Fig. 3). In most process annealing a greater variation in grain size is allowed than in finish annealing. The heating zones for process annealing can, therefore, be operated with some temperature differential between furnace and work with correspondingly high rate of heat transfer and increased production capacity. If the same furnace is utilized for both operations, the slow-cooling zone is of sufficient length to "bright cool" the finish annealed work only. A short water quench section just ahead of the discharge door will provide the additional cooling required for breakdown annealing.

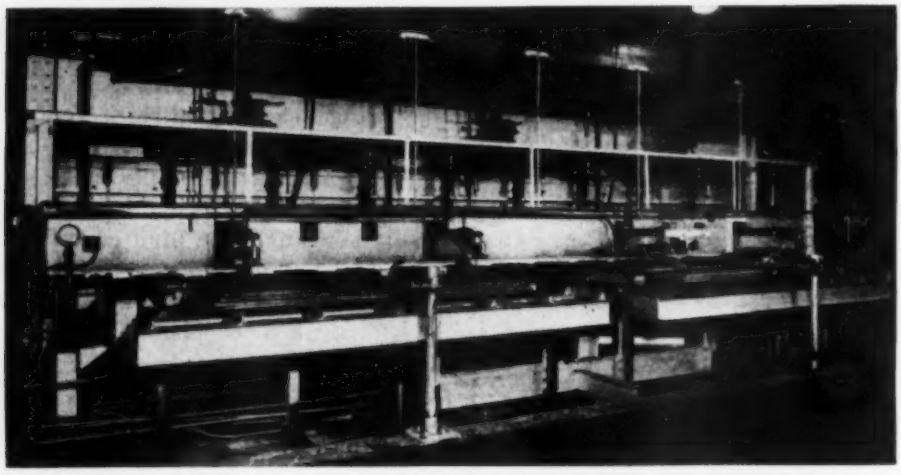

Fig. 4 — Front View of Slab Heater in Copper and Brass Mill. Slabs are piled by crane on elevating tables, and then pulled off one by one, sideways, onto a walking-beam conveyer. Roof is suspended from overhead beams so interior of furnace hearth is entirely clear

(Finish annealing, of course, does not use the quench. A similar arrangement is employed also in process annealing those alloys which cannot be quenched directly from the maximum annealing temperature.)

Types of Controlled Atmosphere Furnaces

Aside from the general classification into batch or continuous types and direct or indirect-fired types, furnaces are commonly designated by the conveyer which carries the work. On this basis, the same types of furnaces are encountered in the nonferrous and in the ferrous metal industry. Choice of the conveyer or furnace type is governed by the class and shape of work to be heat treated. A brief yet comprehensive description of the various types seems possible if we follow the three principal classes of nonferrous products, namely, sheet and strip, tubing, and wire, through their successive stages of production.

Sheet and Strip Furnaces — In the sheet and strip mill the first heating operation is performed on the large cakes coming from the casting shop. Cakes are passed through a continuous pusher-type heater and then rolled into elongated thinner slabs. The latter are annealed for cold rolling in a short, fully mechanized walking-beam furnace (Fig. 4) through which they are conveyed sideways, one high. (More recently, also, continuous roller-hearth furnaces have been used.) Upon leaving the furnace, the slabs are cooled by water spray from top and bottom.

Little attention is paid to atmosphere in most of the cake and slab heaters. In walking-beam furnaces the total time is quite short, namely, about 5 min. for a $\frac{15}{16}$-in. slab; very little scale is formed. The total time for cakes is much longer because of their heavier thickness; this obviously forms considerable scale. Scaling during hot rolling is unavoidable and the imperfections on the slab's surface are completely removed by scarfing. Yet with a little more care in furnace construction and in the adjustment of the direct firing burners, scaling during heating can be eliminated, and many costly shutdowns to clean out the scale could thus be avoided and furnace maintenance reduced to a minimum.

Use of controlled-atmosphere furnaces generally starts after the rundown mill and the metal is annealed in coils for further rolling. Convection-heated batch-type furnaces are found in merchant mills which produce a wide variety of different alloys in many different gages. Wherever large tonnages of the same material are turned out, the continuous roller-hearth furnace is employed to greater advantage and economy. These furnaces are direct-fired with a number of burners, but ample gas recirculation of the furnace gases is provided by internal fans. At the discharge end of the heating zone, the coils are water-spray quenched before coming out into the

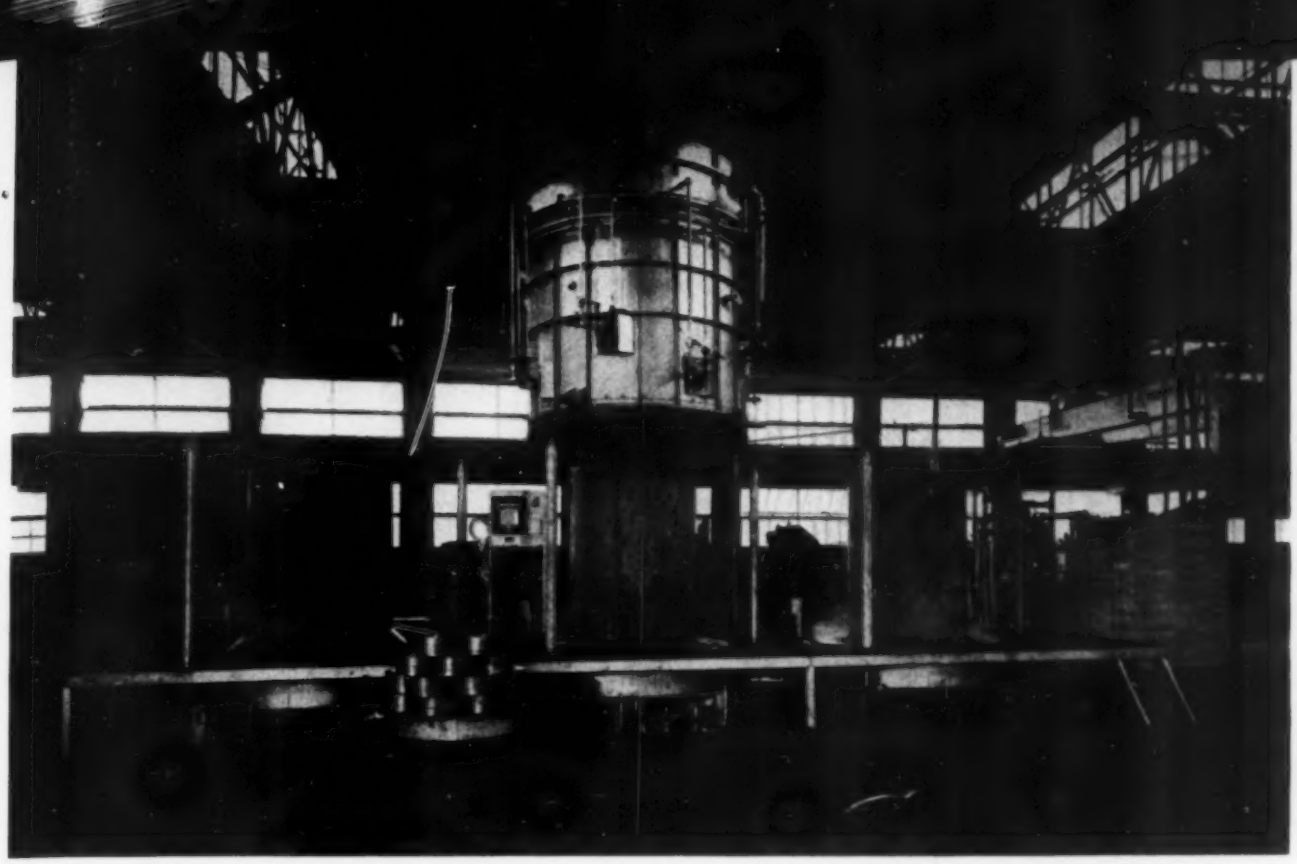

Fig. 5 — Bell-Type Unit (Three Stands and Gas Generator) for Bright Annealing of Copper Coils. Three bases, three sheet covers, one heating unit shown suspended by overhead crane

air and being passed on to mills for further cold rolling.

In both batch and continuous furnaces used at this stage, the coils are clean annealed and therefore require light pickling only. A clean rather than bright surface is preferred, because pickling etches and roughens the surface sufficiently to give better adherence of the rolling oil. The strip is still thick enough so further reduction irons out any surface roughness before the ready-to-finish stage is reached.

Full atmosphere control is applied in all ready-to-finish and finish annealing operations. Because of its extreme adaptability, both as to the size of the various loads to be heat treated and the different annealing temperatures required for the various alloys, the bell type of bright annealing furnace is today the standard furnace in the finishing department. Such a unit (illustrated above in Fig. 5) consists of one direct-fired portable heating cover, three bases equipped with recirculating fans, and three inner covers made of steel or alloy sheet, depending upon the maximum working temperature.

When bright annealing copper, a dual-atmosphere gas system is favored. During the heating cycle, steam is introduced into the inner cover to carry off the vaporized rolling oil, which usually contains some sulphur. After proper soaking at temperature, the heating cover is removed and the steam inside the inner cover and surrounding the metal being processed is replaced by a dry protective atmosphere (produced in a separate gas generator) and maintained there during the entire cooling cycle. To speed the cooling, the outside of the inner cover is sprayed with water, which runs down into the water seal between base and inner cover. Copper coils annealed in this manner come out perfectly dry and bright.

For most brass coils, the same procedure is followed except for the elimination of the steam atmosphere during the heating cycle. A wet seal is also used since the inner cover is usually water sprayed in order to shorten the cooling period. A dry seal and cooling without water-spraying is necessary for certain alloys, such as silicon brass, which, for bright annealing, require a bone-dry atmosphere free from CO_2.

Modern production methods dealing with ever-increasing tonnages of a single metal or alloy of the same size and thickness favor continuous bright annealing, as in the roller-hearth furnace, through which, as shown in Fig. 6, the coils are carried on perforated trays. Roller hearth furnaces eliminate the damage to coils that occurs when they are piled on the base of a bell annealer, and assure a more exact uniformity of anneal, since each coil is subjected to the same time-temperature cycle as it advances through the furnace chamber. Furthermore, modern research appears to have developed rolling oils free from sulphur, thus eliminating the necessity for a dual atmosphere which, for evident reasons, presents a difficult problem in a continuous furnace.

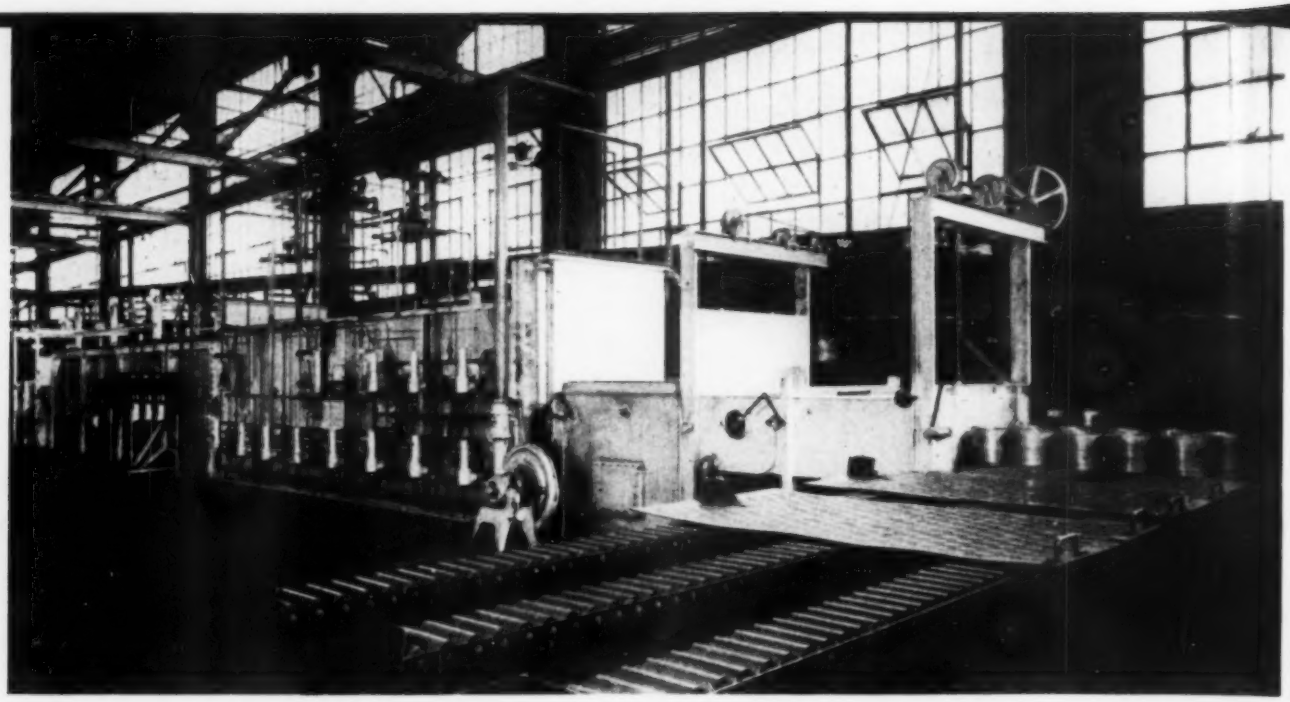

Fig. 6 — Charge End of Roller Hearth Continuous Furnace for Bright Annealing of Copper Coils. Heating is by radiant tubes. Note double entrance vestibule to conserve atmosphere gas

Continuous annealing of strip, threaded endwise through the furnace rather than in coils, is becoming more and more popular. Certain materials, especially very wide strip, call for extreme uniformity of grain size and surface condition across their full width. Continuous strip annealing in a catenary-type furnace (Fig. 7) or its equivalent appears the only way to achieve this end. Such furnaces may be either direct-fired or of controlled atmosphere. Strip is water quenched as it emerges from the direct-fired furnace and then pickled in an acid tank installed in line.

Large individual sheets of nonferrous metals are conveniently annealed in conveyer furnaces wherein the conveyer consists of several individual chains held on constant centers by spacer bars provided with suitable projecting lugs upon which the sheets rest on their way through the furnace. This method of handling assures good exposure of both top and bottom of the sheet to the protective atmosphere. In annealing copper sheets, bright or salmon finish can be produced at will by merely changing the air-gas ratio in the direct-fired burners.

Tube Furnaces — In the tube mill, the rough shell (from which the tubing is made by subsequent drawing or tube-reducing operations) is produced either by extruding relatively short but large diameter billets, or by piercing elongated cylindrical billets of smaller diameter. The method of producing the shells determines the type of billet heater.

For heating billets for the extrusion press, the direct-fired rotary-hearth furnace is gradually displacing the pusher-type furnace and the still older inclined-hearth furnace in which the billets roll down. As with sheet or strip, no particular control of the atmosphere is exercised in billet heaters, mainly for the reason that only the sound core of the billet is extruded, leaving behind in the press cavity the outer shell of the billet. Its condition, therefore, may be oxidized. Furthermore, any loose scale which may drop off the bil-

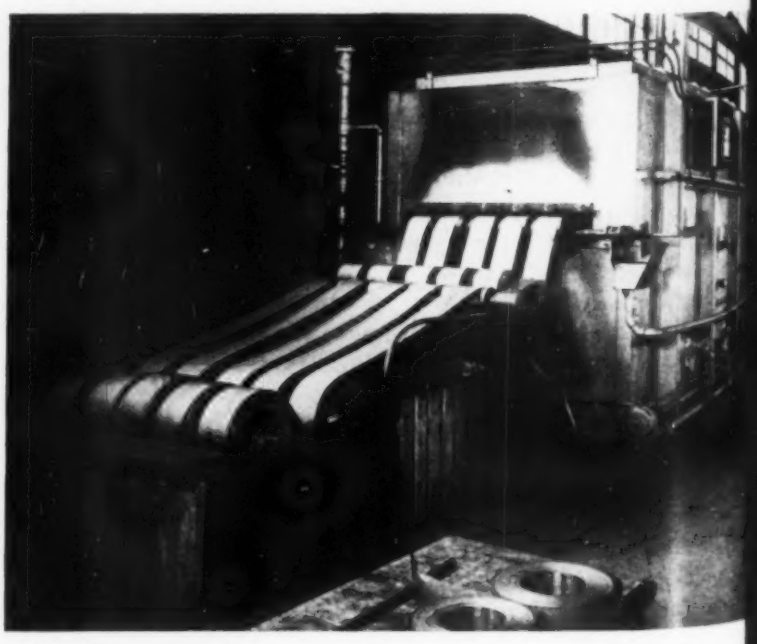

Fig. 7 — Charge End of a Continuous Annealing Furnace for Brass Strip. The strip is supported by rollers at inlet and discharge end, and hangs freely in the heating chamber. Steam at far end of furnace comes from flash pickling tank

lets in the furnace cannot damage the machinery for rotating the hearth, since the vital parts are located outside the furnace chamber.

For the piercing mill, the long round billets are heated in direct-fired walking-beam furnaces, or in double-screw conveyer furnaces. To prevent damage to the moving conveyer parts within the heating chambers, it is essential to eliminate scaling by proper furnace design and adjustment of burner equipment; controlled atmosphere furnaces are therefore used. (See Fig. 8.)

After one or more passes on the drawbench or reduction in the tube reducer, the cold worked tubes must be softened again. This "breakdown anneal" is usually done in continuous roller-hearth furnaces very similar in appearance, size and construction to the bright annealing furnace shown in Fig. 3. With few exceptions, the furnaces are direct fired or of the convection type using one or two large burners located in the path of the recirculating gas.

A recent modification, which has rapidly increased in favor with tube mill operators, is the installation of a preheater — in effect, a short, high-temperature heating chamber located at the entrance end of the furnace proper in which the incoming work, traveling at a constant speed, is heated rapidly either by high-temperature radiation, by direct impingement of hot gases, or by a combination of both. Thus it quickly approaches the correct annealing temperature. The long heating zone in the furnace proper brings the temperature accurately to the desired point and holds the tube throughout the necessary soaking time. Preheaters are in use today which almost double the rated production capacity of conventional-type furnaces. Their obvious chief advantage lies in the exceedingly high heating capacity in a very short distance, which results in a considerable saving of valuable floor space.

As mentioned earlier, discoloration is permissible during breakdown annealing, because it normally disappears completely in further processing. This enables the metallurgist to choose the most efficient, yet cheapest method of cooling as far as investment and floor space are concerned. A short chamber in which the work is water-sprayed from top and bottom is usually placed at the exit end of the heating zone. For certain alloys, such as leaded brasses, quenching from the maximum annealing temperature is detrimental. It then becomes necessary to insert a slow-cooling zone between the heating zone and the water quench.

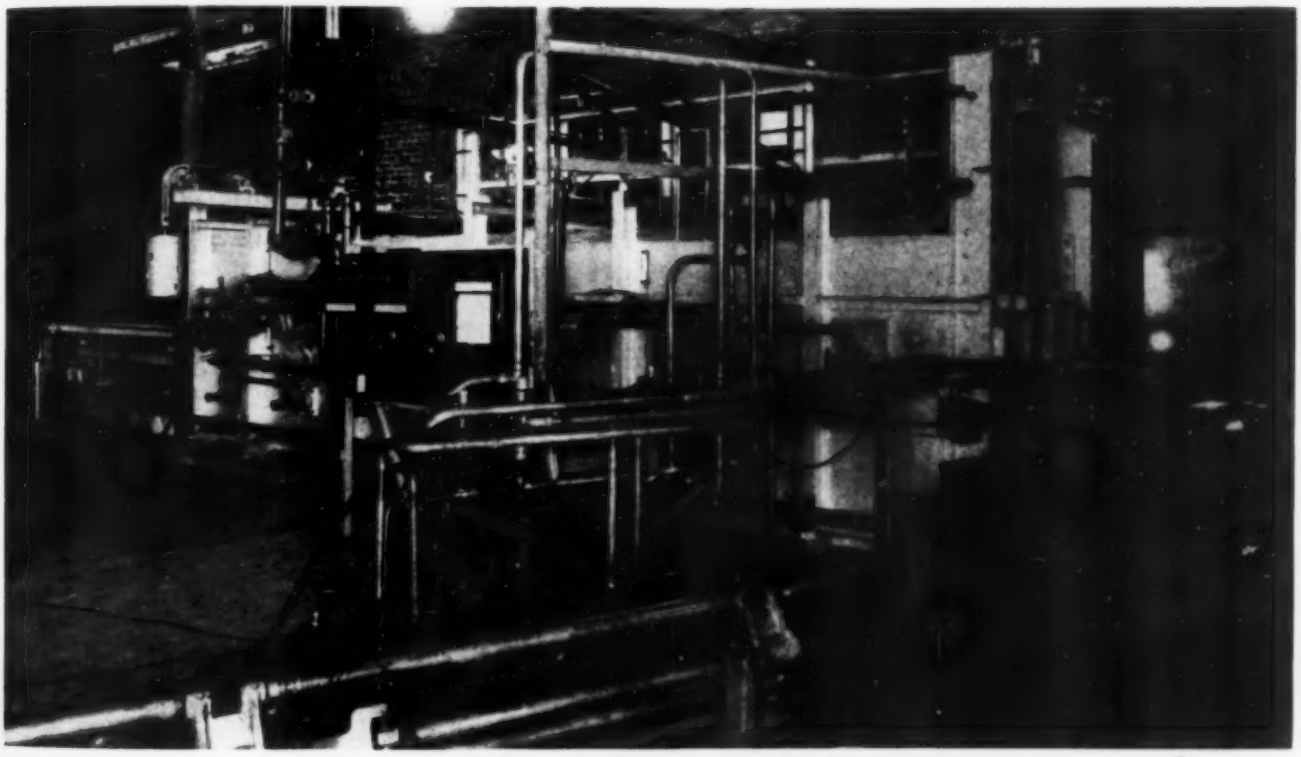

Fig. 8 — Direct-Fired Heater (Walking-Beam Type) for Copper Billets. Run-out mechanism on billet piercer shown in foreground

The same cooling arrangement serves well in many finish bright-annealing operations where some water staining is allowable. However, where a perfectly bright and dry finish on delivered tubing is essential, such as tubing for refrigeration systems, the longer zone cooled by forced convection, or the still longer water-jacketed zone must be installed. In any event, the continuous roller-hearth furnace is today being generally accepted as the best type for finish bright annealing of tubing, whether it is in coil form or in straight lengths, gradually replacing the mesh belt furnace which was favored only a few years ago.

Some differences of opinion still exist, among the various manufacturers of nonferrous tubing, as to the best method of firing the heating zone. The proponents of the direct-fired, convection-type furnace insist that the high humidity of the immediate products of combustion has a decided advantage in cleansing the surface of the work while it is being heated. Others claim that high humidity leads to condensation on the incoming cold work, resulting in some water "markings" — to be distinguished from water "staining" which occurs at the discharge end exclusively. The latter school of thought, therefore, favors the indirect-fired furnace, such as the radiant-tube fired heating zone with internal recirculating fans, usually installed in the roof of the heating chamber. A fairly dry atmosphere (40° F. dew point) prepared in a suitable gas generator is then furnished.

Wire mill furnaces are substantially the same as those used in the tube mill. The only difference lies in the handling of the work which is coiled on flanged spools of various sizes, depending upon the wire gage. Both batch-type bell-annealers or continuous-type indirect-fired roller-hearth furnaces are employed for process annealing and finish bright-annealing in a reasonably dry prepared gas atmosphere.

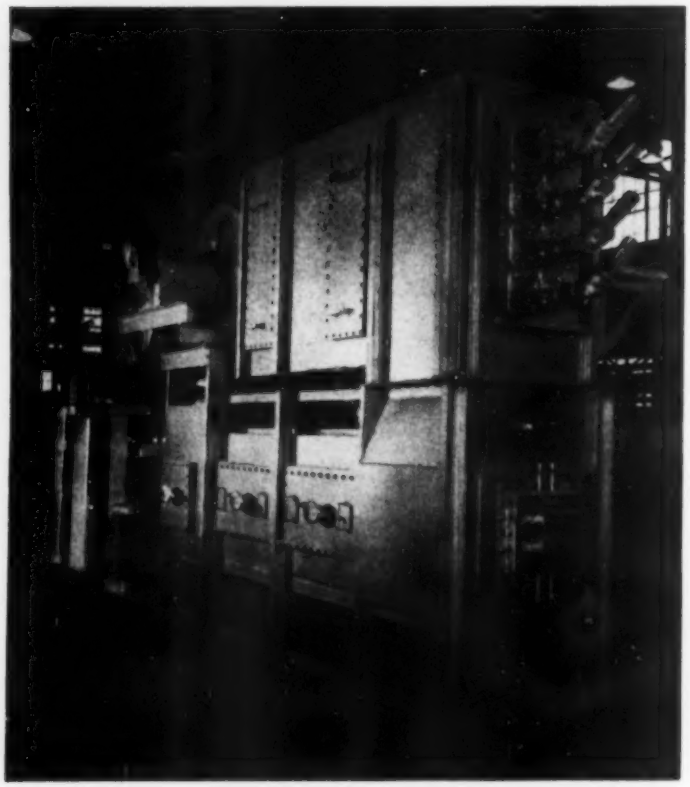

Fig. 9 — Continuous Bright Annealer for Double Strand of Precious Metal Strip. Entrance end shows heater (above) for recirculating gas — partially burned ammonia, completely dehydrated, analyzing 90% N_2 and 10% H_2. Short cooling zone is at far end (left side of photograph), wherein strip is cooled by same atmosphere in separate circuit — chamber to cooler to fan to chamber

Furnaces for Precious Metals

The precious metal industry, turning out its finished products in ounces rather than in tons, obviously utilizes much smaller, although similar, types of furnaces than its sister industries in the nonferrous field. In many respects, this industry may be even considered the latest addition to the nonferrous metal industries that have converted operations to complete mechanization and fully controlled atmosphere furnaces.

It is only since the closing days of World War II that the precious metal industry has begun to replace antiquated furnace equipment (which involved much manual operation) with the most modern types of furnaces originally developed for other metallurgical branches. Because of the great care required to prevent any surface blemishes and to assure the utmost luster of its finished materials, the precious metal industry is threatening to surpass others in the general use of controlled atmospheres. It is only quite recently that a complete knowledge of the exact requiremeats of the atmosphere, its composition and proper application for treating the various alloys to best advantage, has been acquired by the cooperative efforts of furnace users and furnace builders. With the experience gained in two decades of work in the steel and copper and brass and nickel industries, the furnace builder has available all information necessary for incorporating into new furnace installations for precious metals the latest heating and cooling methods, conveying mechanisms, furnace details, atmosphere generator design and control equipment.

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Varying in length from 11 to 16 feet, and approximately 12 inches wide these units have been cast in two sections and welded together to give gas-tight, one-piece construction—demonstrating the versatility of Nichrome, which can be cast, rolled, drawn, formed and welded to produce numerous components for use under all conditions of high temperature operation.

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Personals

Election of **A. B. Kinzel** as president of Union Carbide and Carbon Research Laboratories, Inc., has been announced. Dr. Kinzel has been associated with the parent organization, Union Carbide and Carbon Corp., since 1926, serving in various capacities where his great ability as a metallurgist has been used to advantage.

American Brake Shoe Co. announces that **John A. Fellows** has been appointed assistant chief metallurgist at the research center in Mahwah, N. J. Mr. Fellows returns to Brake Shoe after 2½ years in the atomic energy field and 1½ years with Union Carbide and Carbon Corp.

George W. Strahan, formerly with the sales department of the International Nickel Co. and a member of the executive committee of the New York Chapter, has taken the position of sales manager of Westlectric Castings, Inc., Los Angeles.

Eutectic Welding Alloys Corp. announces the appointment of **Theodore I. Leston** as vice-president in charge of production. As a member of the research laboratory staff Mr. Leston has guided several new arc welding electrodes and alloys through the pilot plant stages to production.

E. Richard Walter has been promoted from chief metallurgist of Powdered Metal Products, Franklin Park, Ill., to sales manager of the same company.

C. M. Binney, who has been with Allegheny Ludlum Steel Corp.'s sales force since October 1946, has been appointed assistant district manager of the New York sales district.

Promotions in the American Steel & Wire Co. elevate **Nelson W. Dempsey** to the position of general superintendent at Waukegan works and **Vernon L. Strohm** to division superintendent of wire mills, to fill the vacancy left by Mr. Dempsey.

Crucible Steel Co. of America announces the appointment of **James D. Glenn**, formerly with Sharon Steel and Eastern Stainless Steel Corp., as general manager of stainless steel sales. Mr. Glenn's headquarters will be in New York City.

Lloyd R. Cooper has been named director of research for Heppenstall Co., Pittsburgh. Mr. Cooper has been with the Heppenstall organization since 1942 and has been acting director of research for the past 1½ years.

Frank G. Benford has been made assistant plant manager of the West Leechburg, Pa., plant of Allegheny Ludlum Steel Corp. Previously with General Electric Co. in Schenectady, N. Y., he joined Allegheny Ludlum as chief metallurgist of the West Leechburg plant in 1945.

John W. Frazier, formerly metallurgical engineer and assistant chief process engineer for Jack & Heintz Precision Industries, Inc., is now connected with John Ek Industries, Inc., Guilford, Conn., as metallurgical engineer.

J. Darrell Harvey has recently returned from Korea where he served as chief of industry of the United States Military Government and has been made assistant to the commanding general of Warner Robins Air Materiel Area, Robins Field, Ga.

Bani R. Banerjee is leaving Yale University to join the faculty of the Illinois Institute of Technology, Chicago.

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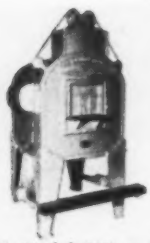
No. 2 Model "Y" Furnace for hardening tungsten, moly and cobalt high speed steels. Five sizes.



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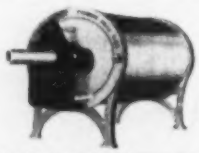

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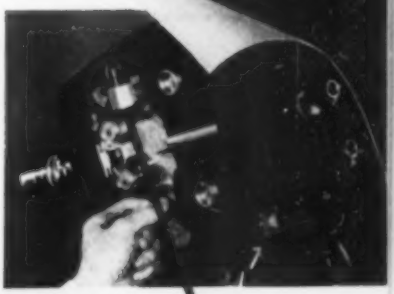

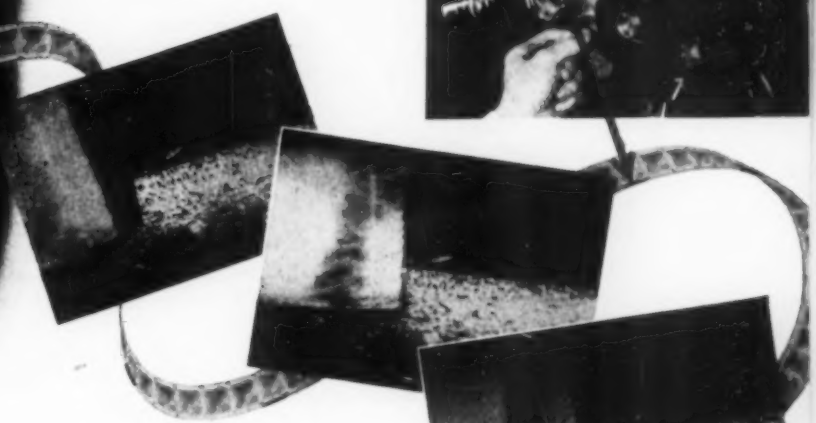

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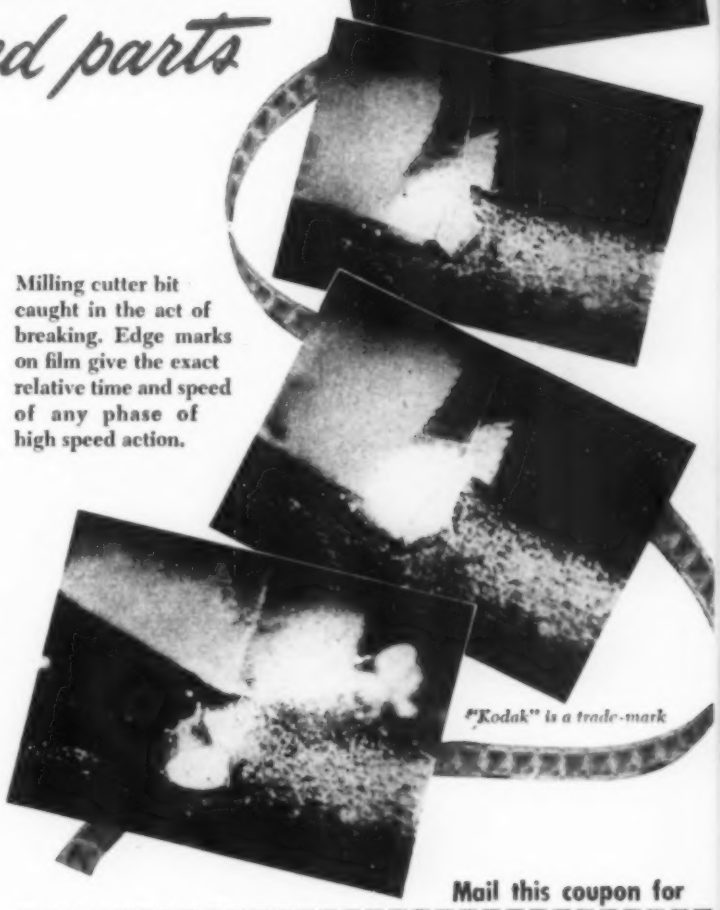

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Personals

P. K. Koh has been appointed associate director of research in charge of tool and die steel and allied products of Allegheny Ludlum Steel Corp., with offices in the Brackenridge, Pa., plant. He was in the metallurgical research department of Standard Oil Co. of Indiana before joining Allegheny Ludlum.

The Midvale Co. announces the appointment of **Homer C. Lackey** as district sales manager in Cleveland. Mr. Lackey has been in various production and sales assignments with Midvale since 1930.

The retirement of **William A. Fowler** from the position of general manager of the Columbus plant of the Timken Roller Bearing Co., after 37 years with the company, has brought about the promotion of **L. D. Gable**, formerly factory manager of the Columbus plant, to general manager.

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Haig Solakian, formerly vice-president, chief metallurgist and director of research for the A. F. Holden Co., has recently been appointed president of the John Ek Industries, Inc., Guilford, Conn.

J. L. Burns, past president of the Chicago Chapter and partner of Booz, Allen & Hamilton, has moved his headquarters from Chicago to New York. Mr. Burns is also a director of the Globe Steel Tube Co. and of R. R. Robertson Co.

J. L. Aston is now at the University of Sheffield doing research on high-speed heat treatment of steel.

Leland Brewster Howard is now research engineer with American Saw & Mfg. Co., Springfield, Mass.

Frank F. Joyal has left the U. S. Marine Corps' Supply Depot to resume his education at the University of California where he will work toward a degree in metallurgical engineering.

Robert E. Christian, on completion of graduate work at Carnegie Institute of Technology, has accepted a position with American Brake Shoe Co. metallurgical laboratories where he will study sand-metal problems.

National Lead Co. announces that **George Sathre** has been named metal sales manager for the Cleveland and Pittsburgh branches. Mr. Sathre joined National Lead in 1942, selling in the Cleveland area.

Everett R. Turner, formerly plant metallurgist with Lynn, MacLeod Metallurgy, Ltd., Thetford Mines, Quebec, is now employed by Algoma Steel Corp., Ltd., Sault Ste. Marie, Ont., as a trainee in the open-hearth department.

A. E. Moredock, formerly chief metallurgist, Kelly-Springfield Engineering Co., Allegany Ordnance plant, Cumberland, Md., has been appointed to the technical advisory staff of Revere Copper & Brass, Inc., with headquarters at the Dallas Division, Chicago.

D. L. Palmer has been appointed production manager of Apex Smelting Co., Cleveland division. Mr. Palmer was with National Smelting Co. from 1930 to 1942 and following this was with Basic Magnesium, Inc. He has most recently been a consultant on aluminum foundry problems in the Los Angeles area.

Formerly a research metallurgist with the Magnolia Metal Co. of Elizabeth, N. J., **K. H. Roll** is now with the Lead Industries Assoc., New York.

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Steel Manufacture
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Sodium Sulfite, Anhydrous
Sulfur
Iron Sulfide

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Glauber's Salt
Sulfuric Acid

Pickling
Acetic Acid
Hydrofluoric Acid
Muriatic Acid (Hydrochloric)
Nitric Acid
Sulfuric Acid
Nitre Cake
Sodium Fluoride
Sodium Bifluoride

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Acetic Acid
Perchloric Acid
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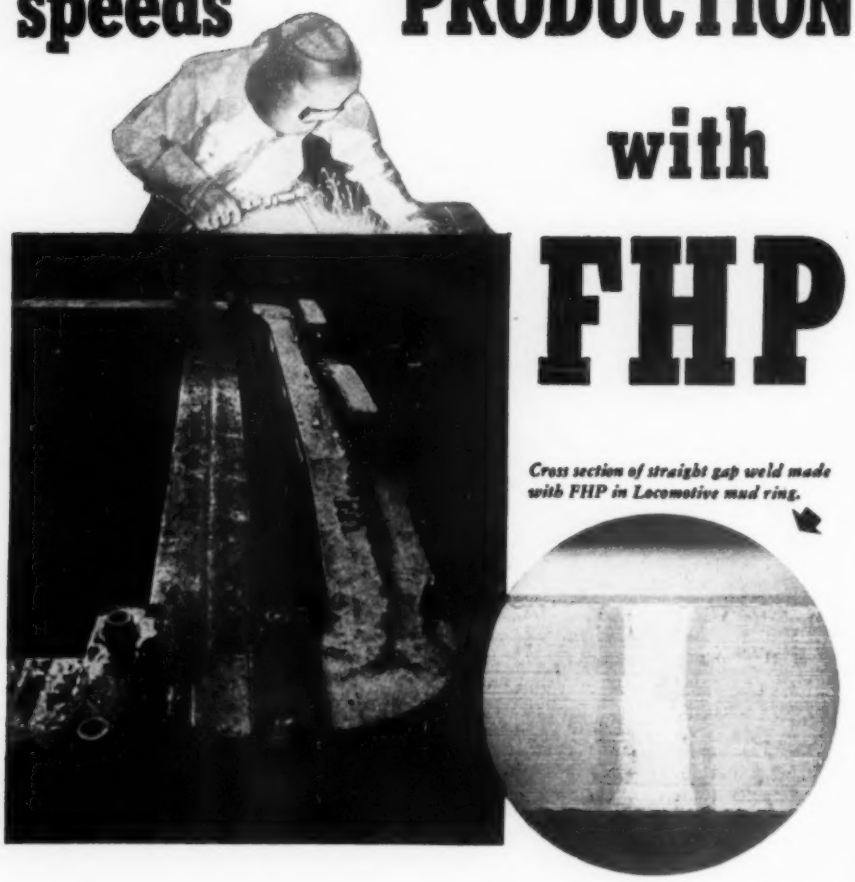

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Personals

Henry Wilmot has been transferred by Shell Oil Co., Inc., from the New York office where he was technical representative of the lubricants department to the Chicago division where he will be division lubricants engineer.

R. W. Waring is now assistant chief engineer of the Bullard Co. of Bridgeport, Conn.

Paul P. Bauernschmid has left the Chandler-Evans Div., Niles-Bement-Pond Co., to join the engineering staff of the International Silver Co., Meriden, Conn., as design engineer.

J. A. Rolston has accepted a position with the English Mica Co., Spruce Pine, N. C., as plant project engineer.

Franklin Page, Jr., formerly of Solar Aircraft Co., is now attending the graduate school at California Institute of Technology, working toward his M.S. degree in chemical engineering.

John P. Denny has left Battelle Memorial Institute to do graduate work in metallurgy at the University of Utah, Salt Lake City, Utah.

Alvin H. Barrows has been transferred by Carnegie-Illinois Steel Corp. from the sales department of the general offices in Pittsburgh to the district sales office in Indianapolis, Ind.

Frederick Gerson, after completion of seven months of research in the eastern United States on behalf of Almex, Ltd., Birmingham, England, has now joined the company's plant at Birmingham as research engineer.

Resigning from Sun Oil Co. as industrial products representative for western Massachusetts and Vermont, **R. A. Laakso** has accepted a position in the sales department of Graton & Knight Co., Worcester, Mass.

Martin D. Rosenthal, formerly with the Office of Naval Research, Chicago branch, is now chemical engineer with General Electric X-Ray Corp.'s new plant in Milwaukee.

S. R. Perkins is now staff engineer and consultant with Booz, Allen & Hamilton, Chicago, a firm engaged in management consultant and engineering work.

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Heavily loaded gears, shafts, pinions etc. and carburized parts used in oil well drilling industry.	4815, 4820	U·S·S SuperKore B
Gears, shafts, pinions, etc.	4317, 4320	U·S·S SuperKore C

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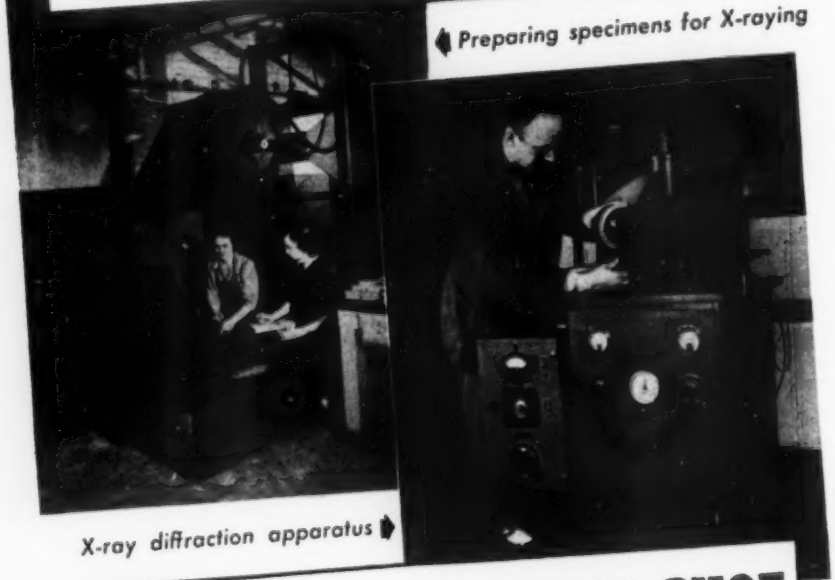

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Personals

James E. Ubben, formerly development metallurgist with the Timken Roller Bearing Co., has taken a position as metallurgist with Emsco Derrick & Equipment Co. in Dallas, Texas.

Following graduation from the Colorado School of Mines, **Robert E. Michaelis** has joined the Carnegie-Illinois Steel Corp. as spectrographer, Pittsburgh research laboratory.

Carl E. Bartz has recently been appointed sales manager in the Cincinnati territory for Columbia Steel & Shafting Co., Edgar T. Ward's Sons Co. Div. and Summerill Tubing Co. Div. He has been representing these companies for the past 19 years, most recently in Syracuse, N. Y.

David A. Vermilyea, formerly metallurgical engineer at E. I. du Pont de Nemours and Co., has accepted a teaching position at Rensselaer Polytechnic Institute, where he will also continue graduate studies.

Wong Ju Sun is leaving for China where he expects to be associated with the National Resources Commission as metallurgical engineer.

James Walker, formerly with Consolidated-Vultee Aircraft Co., is now assistant superintendent of the Worcester Pressed Steel Co., Worcester, Mass.

Donald R. Steele is now plant metallurgist with the engineered castings division of the American Brake Shoe Co., Rochester, N. Y.

Richmond C. Neff has received an appointment as instructor of engineering mechanics at Purdue University, Lafayette, Ind.

Resigning from Canadair, Ltd., of Montreal, **Walter Banas** has enrolled at the University of Colorado to continue his engineering and business administration courses.

Phil P. Haney, formerly with Consolidated-Vultee Aircraft Co., is now in the mechanical engineering department of the N.A.C.A., Langley Field, Va.

Wm. J. Fretague has enrolled at the University of Notre Dame, where he has a teaching fellowship in metallurgy. Before entering the service, he was metallurgist at Frigidaire Div., General Motors Corp., in Dayton, Ohio.

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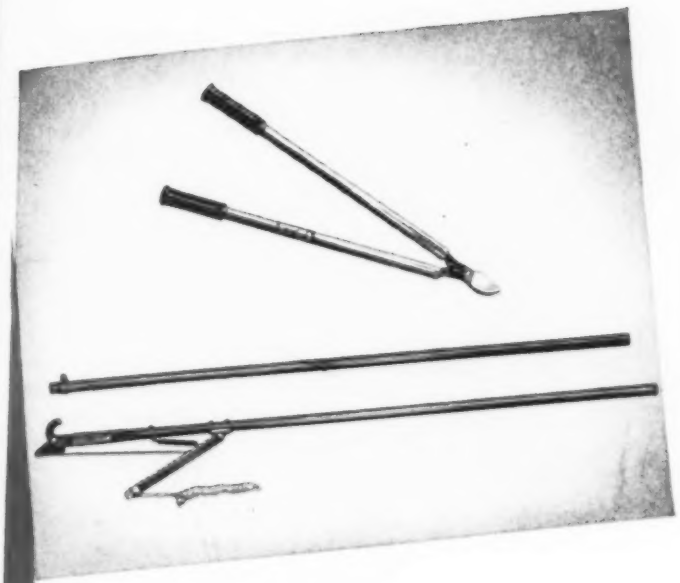
MANUALLY HANDLED EQUIPMENT



PRUNING SHEARS, HEDGE SHEARS AND TREE TRIMMERS

PROBLEM

The breaking of a wooden handle while operating a pair of pruning shears could mean serious personal injury. A far-sighted manufacturer began to look for a material that was more durable yet possessed the necessary strength. In addition it was important that the new material be in plentiful supply since his search was prompted by the scarcity of high grade white ash and hickory. It was also desirable to lighten the over-all weight of the pruning shears.

During the past two years the manufacturer has been using magnesium handles on five different products and there have been no instances of breakage. Since magnesium is not subject to warping or splintering and has an excellent combination of light weight, strength and stiffness, it is ideally suited to this application. The slight additional cost of these magnesium handles is more than offset by these advantages. Magnesium extruded tubing is simple to fabricate and has only to be riveted to the pruner head to make a firm attachment. Adding an enamel coating and a pair of hand grips cemented on the ends completes the finished product.

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Ceramic Turbine Blades*

IN the gradual merging of the whitewares and refractory fields, ceramics is no longer limited to silicates. There has even been a diffusion of ceramics into metallurgy, and the result has been called the field of "cerametallics". Its utility is for prime movers operating at high temperatures. In this respect most consideration has been given to thorium oxide, magnesium oxide, beryllium oxide, and carbon.

As a wartime use, some interesting data were given on the V-2 rocket. It burned 300 lb. of fuel per sec. and developed a flame temperature of 5000° F. (2800° C.) and a pressure of 300 to 500 psi. in the combustion chamber. It descended at a speed of around 7000 ft. per sec. (over 60 miles per min.)!

Some properties necessary for ceramic materials for use in nozzles for rockets are a minimum melting point of 4000° F. (2200° C.), excellent heat shock resistance, and superior corrosion resistance. Erosion resistance is not important as long as solid particles are not present in fuel or combustion gases. "Ram jets" would attain speeds of 1500 miles per hr. and temperatures beyond the flame head may reach 3500 to 4000° F. (2000 to 2200° C.). On the other hand, the turbo-jet engine operates with a high temperature zone of only 1200 to 1500° F. (650 to 800° C.). The pressure is not too severe, but the temperature is high enough to require special attention to strength and resistance to thermal shock. Since thermal efficiency increases with operating temperature, the engineers would like to operate the turbo-jet at 1900° F. (1030° C.), but adequate materials are not yet available for construction. In such an engine, the tip speed of the turbine buckets would be about 1000 ft. per sec.; materials therefor should have a creep rate of less than 0.0005% per hr. Under these conditions a ceramic turbine blade material of density 3 would have a root stress of approximately 18,500 psi.

(Continued on page 414)

*Abstract of "Simple Oxide Porcelains for Jet Planes and Projectiles", by R. F. Geller, National Bureau of Standards. Paper before the American Ceramic Society, refractories division, October 1947.

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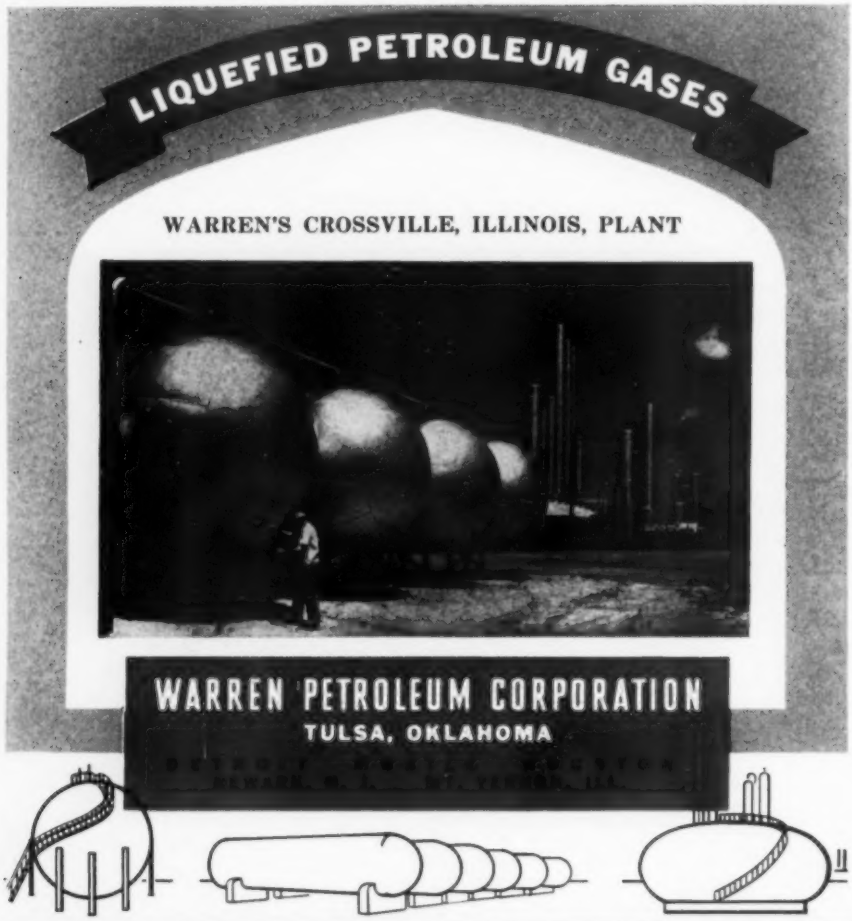

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Turbine Blades

(Continued from page 413)

The Bureau of Standards has been investigating ceramic materials to withstand these conditions of temperature and stress. Ordinary high-voltage electrical porcelain was investigated by Martin in 1936, who measured a creep of 0.2% at 1650° F. under a stress of 1000 psi. in 10 hr. The Germans reported that their alumina bodies had a tensile strength of 6000 psi. Principal work at the Bureau was on the system of beryllium oxide, magnesium oxide, and zirconium oxide. It contains three binary eutectics and one ternary eutectic. The eutectic between beryllium oxide and zirconium oxide is at 4060° F. (2240° C.); for beryllium and magnesium oxides it is at 3350° F. (1845° C.); and the magnesium-zirconium oxide eutectic is at 3920° F. (2160° C.). The ternary eutectic of the three oxides is at 3065° F. (1685° C.). Solid solution occurs between zirconium oxide and beryllium oxide.

A region roughly defined as containing not more than 50% magnesia, with the balance beryllium oxide or zirconium oxide (or both) consisted of mixtures which the author stated could be vitrified in a commercial kiln; mixtures lying in the region above the 50% magnesia line of the triaxial diagram could not be vitrified in commercial furnaces.

Porcelains were made in this system which vitrified from 2700 to 2900° F. (1500 to 1600° C.), and stress-creep curves were shown for tests conducted at elevated temperatures. In general, at relatively low temperatures — approximately 1500° F. (800° C.) — an increase in stress did not cause a large increase in creep; however, at higher temperatures — approximately 1800° F. (980° C.) — an increase in stress caused a large increase in creep. Increases in temperature at a constant stress also cause relatively large increases in creep.

Creep tests and tensile tests at high temperatures were made on rods 8 in. long, with a central section 4 in. long turned down to a diameter of about ¼ in. These were mounted in ceramic grips and adjusted in a platinum-wound furnace. The furnace had glass windows on two sides for observing the central section of the test specimen. A platinum *(Cont. on p. 416)*

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This syrup pump for soda fountains is readily accepted by health authorities because it's made of stainless steel.

Like many stainless products, however, this pump requires more than just a single steel. *Three* different stainless types are used—each for a specific advantage. The plunger assembly is Type 303 bar (machinability) . . . the cover plate and deep drawn cup are 302 sheet (ductility) . . . and the two fluid lines are 304 tubing (weldability). Despite this mixed requirement, all 3 forms, in the necessary analyses, are obtained *overnight* from Frasse warehouse.

In fact, you can choose from *seven* stainless types when you work from Frasse stocks. And you can work with sheets, plates, strip, tube, pipe—everything from bars to welding electrodes. All are immediately available stock items.

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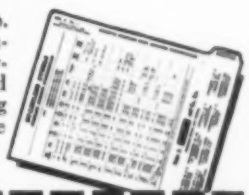

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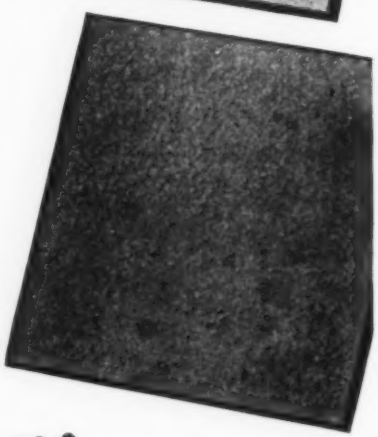

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Turbine Blades

(From p. 414) extensometer gage was attached, marked suitably, and creep was measured to 0.00001 in. at 1700° F.

A good composition from the point of view of low creep under high stress at 1700° F. (925° C.) is 80% zirconia, 10% beryllium oxide, and 10% magnesia. It was said that this is a good material from which to make supports and grips.

National Bureau of Standards' "body No. 4811" was not quite vitrified at 3100° F. (1700° C.). An addition of 2% lime produced a vitreous body at 2730° F. (1500° C.). This lime addition lowered the thermal conductivity of the body, but 4% of magnesia in place of the lime *increased* the thermal conductivity; in fact, the magnesia-bearing body had a thermal conductivity eight times that of the lime-bearing body. The effect of these additions on the tensile and creep properties is not known, as apparently tensile and creep data were not obtained on the original No. 4811. Its modulus of rupture at room temperature is approximately 25,000 psi. and drops to about 14,000 psi. at 1800° F. (980° C.). No effect on the modulus of rupture was occasioned by ten quenches from 1700° F. (925° C.) to room temperature by an air blast. Data on creep and tensile properties of a number of ceramics are given in the paper.

The author believes that the temperature of crystallization of alumina is as critical as the melting point. The tensile properties of pure alumina have not been determined, because of an inability to obtain proper specimens.

New Refractories*

SMALL refractory specialties in a variety of shapes and a surprising range of compositions are now commercially marketed. Consideration is being given, by carload purchasers of *(Cont. on p. 418)*

*Abstract of "An Introduction to the Refractory Oxides", by R. E. Birch, Harbison-Walker Refractories Co. Paper before the American Ceramic Society, refractories division, October 1947.

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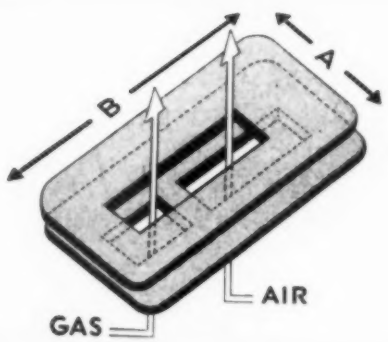

SEE HOW SIMPLE IT IS... Upper slide with one port overlaps Gas and Air ports in lower slide. Fuel demand automatically moves upper slide in direction A-A to increase or decrease gas and air in precisely equal proportions. Manual adjustment by micrometer screw control and vernier scale in direction B-B adjusts proportion of gas and air. You lock it and there it stays until you change it. Simple! Adjustable! Fixable! A self-cleaner, too, and like the rest of the KEMP Industrial Carburetors it requires virtually no maintenance.

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New Refractories

(From p. 416) refractories, as to which of these newest refractories, now available only in the laboratory, will eventually be available in large tonnage.

Starting with the requirement that the melting point must be 3300° F. (1800° C.) or higher, there are still at least 20 chemical elements which yield compounds that can qualify. Data on their oxides are given in Table I.

Table I — Data on Refractory Oxides

Element	Density	Cost per Pound	9-In. Brick	
			Weight	Cost
Beryllium	3.0	$4.00	8.2 lb.	$25.00
Zinc	5.5	0.075	15.0	1.10
Magnesium	3.6	0.05	10.0	0.50
Strontium	4.7	0.50	12.9	6.50
Barium	5.7	0.10	15.6	1.56
Calcium	3.3	0.005	9.0	0.05
Aluminum	4.0	0.055	10.0	0.55
Cerium	7.6	0.82	20.8	17.00
Thorium	9.7	7.00	26.5	185.00
Titanium	4.9	0.09	12.4	1.10
Zirconium	5.7	0.90	15.6	14.00
Yttrium	4.8	12.50	13.1	164.00
Lanthanum	6.5	14.00	17.8	250.00
Chromium	5.0	0.25	13.7	3.40
Cobalt	5.7	1.84	15.6	28.60
Nickel	7.4	0.35	20.0	7.00
Uranium	5.6	3.00	15.3	46.00

Table II — Tests at 3000° F. on High Grade Oxides

Oxide	Reaction With Stool of			
	SiO_2	MgO	Chrome	91% Al_2O_3
ZnO	Gone	Gone	Gone	Gone
Ni_2O_3	Fluxed in	Good	Good	Good
CeO_2	Gone	Excellent	Good	Fair
ThO	Good	Excellent	Good	Good
BaO	Dusted, fluxed in	Gone	Extreme fluxing	Fluxed
Cr_2O_3	Good	Good	Good	Good
TiO_2	Fluxed	Poor	Good	Some fluxing
V_2O_5	Gone	Gone	—	Gone
ZrO_2	Good	Noticeable reaction	Good	Good
CoO	Fluxed in	Poor	Good	Mildly fluxed
La_2O_3	?	Powdered	Swelled	Dusted
BeO	Fair	Fair	Good	Good
SrO	Powdered	Powdered	Extreme fluxing	Fluxed

Table I and Table II

Of course, melting points provide only the threshold for the study of new refractories. Before one can be applied intelligently we need to know *(a)* its reactiveness to other materials, *(b)* its stability in furnace atmospheres, *(c)* its thermal expansion, *(d)* its thermal shock resistance, *(e)* its physical strength, *(f)* its thermal conductivity, and *(g)* the existence of industrial hazards such as occur with barium oxide, beryllium oxide, and many other things.

In the development of the super-refractories, three considerations are basic: *(a)* Only materials of the highest purity should be used; *(b)* the brick and probably the raw material would almost surely require firing at 3000° F. (1650° C.) or higher, to remove shrinkage; and *(c)* special test methods — *(Cont. on p. 420)*

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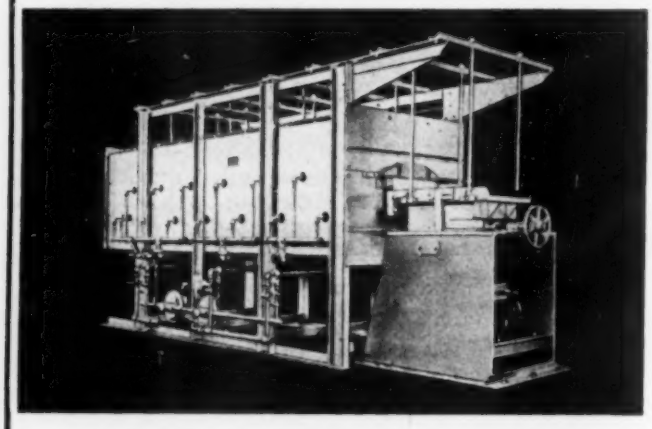

VERSATILE. These furnaces are regularly being used without special provision for work ranging from heavy forgings to phonograph needles.

ATMOSPHERE CONTROL. A completely sealed full muffle permits maintenance of any desired atmosphere.

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The Greenlite on the Wabash Housewarming of Our Indiana Home

e George O. Desautels Company, sales engineers, representing eral Alloys with offices in Indianapolis, Fort Wayne and ncie, stand without equal in results produced for their cus- ers and principals. Their new office building, 2302 North ndian Street, Indianapolis, is literally the house that service lt. No name is better known in industrial Indianapolis than autels and no alloys equal the Q-Alloys he sells.

orge learned the tool maker's trade in New England, fought way up the ladder to President of a drop forge company and n awarded himself the portfolio of "Ambassador of Technical gress" to Indiana industry.

sixtieth birthday was an event in Indiana history. The d ballroom of the Claypool Hotel is still vibrating after ral years.

tween time he piloted the Shell Forging Program at Wash- on for a dollar a year. (We understand he got renegotiated of 86c on the $.)

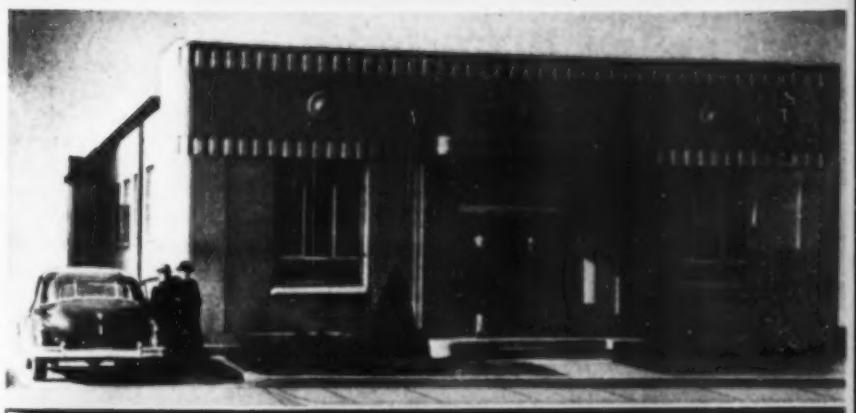
rgaret Rudbeck, who runs the place while George and his Leon, stimulate the salesmen and harass the customers, is d among the top ten of American business women. (She es that she has ever posed for any of the calendars distrib- d by G.O.D. & Co.)

neral Alloys is proud of the Desautels organization and share r enthusiasm in their new home. This modern, air condi- ed and superbly equipped office is George Desautels' expres- of faith in an active and brilliant future for General Alloys' ducts and others under Desautels' pilotage in Indiana.

an age when most men retire, George has just gotten his ond wind".

the pictures shown are a few guests at the Desautels' house- ming. If you know industrial Indiana, you will know the strial leaders assembled for the housewarming.

neral Alloys is proud of the company we keep and who *keep* our representatives and our customers. Their success is ours.



Trains Alter the Best Laid "Ducks" —and Mice and Men

e amphibious yacht "Platypus" came to a blind grade sing in a strange city. The trees hid the warning sign. The n was behind schedule making up time and it caught the duck e under the tail feathers, turning it back into the drivers of engine.

ptain Tony, number one "Dukyot" Skipper, was at the wheel. was thrown through a lucite and stainless steel deck closure, ered concussion of the brain, cracked several vetebrae and "on-the-brink" for several days.

y is now out of the hospital and learning to navigate in a t jacket which he hopes to discard in a few weeks. At s he has been heard to observe: "Locomotives are damn stantial," and "I must have picked the right General Motors duct for collision purposes."

e superstructure of the duck and its fittings were undamaged. have a few spare hulls and will install a new one shortly.

u may be sure we will proceed with greater respect for n Horses". And that the jockey of that one will be counting cks" in his sleep.

s will go down in history as the first shipwreck occurring on a oad track and the first locomotive derailed by a boat.

Long-Range Alloy Buying Returns

e are very proud that General Alloys' sales volume during the 1947 increased at more than twice the rate of the industry. s reflects the fact that users are again *keeping records* on the *-hour-life received from their trays*, pots, furnace parts and -temperature tooling.

neral Alloys' *Engineered Heat and Corrosion Resistant Castings* made and sold for ultimate economy, *not first cost.* They are chased by the largest and most exacting users on the basis perior function and longer life.

y are produced by the "oldest and largest exclusive manu- urer of heat and corrosion resistant castings" and serviced National engineering organization. If you are willing to the slightly increased first cost of higher quality, to get a ower service cost, *we solicit your inquiries.*

New Refractories

(Starts on p. 416) including reheat tests at a minimum of 3300° F. (1800° C.) — will be needed for evaluating the results.

In the commercial production of refractories it is necessary to have a nonreactive base material on which to set it during the burning operation. In some work described, pressed specimens of various oxides were set on silica, magnesite, chrome, and high alumina brick (91% alumina), and reactions observed after holding at 3000° F. (1650° C.) for 5 hr. The yttrium oxide under test (see Table II) was of 80% purity; the others were of 97% minimum and, in most cases, 99%+ purity.

The results on pats of zinc oxide (Table II) left considerable doubt as to its having any value as a refractory. With barium oxide there was evidence of melting before reaction. A likely explanation is the oxidation from BaO (melting point 3500° F. or 1925° C.) to the peroxide BaO_2 (whose melting point is reported to be only 840° F. or 450° C. in oxygen). In the latest report of Geller and associates, it showed that when barium oxide and beryllium oxide were blended in equal parts the resulting mixture fused at 2140° F. (1170° C.) They concluded that a low temperature eutectic between BaO and barium carbonate might be the trouble-maker. It was pointed out that no amount of heating will endow the oxides of lime, strontium, and barium with permanent stability in moist atmospheres. The work reported also indicated that lanthanum oxide belongs within this group.

The possibility of a low melting phase draining from a sample was illustrated by a briquette of 50% Transvaal chrome ore, and 50% dicalcium silicate which, when heated to 2725° F. (1500° C.) had an excellent appearance when burned on a magnesite hearth brick. The same sample, however, was heated on a square of platinum foil to separate it from the hearth brick; thereupon the liquid which could not escape continued to react with the remaining solids to cause almost complete fusion.

The available oxides were tested with a torch for thermal shock resistance. Beryllium oxide had the best thermal shock resistance and cerium oxide the poorest.

Of the 18 materials considered when the tests were started and which had melting points above 3300° F. (1800° C.), four were eliminated due to instability in normal air and four more due to instability in reducing atmospheres. When uranium, hafnium, and yttrium are withdrawn due to unavailability, only seven are left. Chromium oxide, however, can be restored to the list because it is known to yield a refractory which retains its shape at 3300° F. (1800° C.) in normal atmospheres.

Only with alumina and magnesia can enough raw material for a 9-in. straight brick be purchased for $1.00. The chrome and magnesite brick now used cost 30 to 40¢ completely manufactured. The author concluded that for high tonnage refractories of superior refractoriness at a cost within reason it is likely that greatest reliance for the foreseeable future must be upon alumina, magnesite, and chrome ore. Other materials, worth some consideration, are zirconium silicate (zircon) and calcium orthosilicate. The latter is not now available and may, in any event, not live up to the promise held out.

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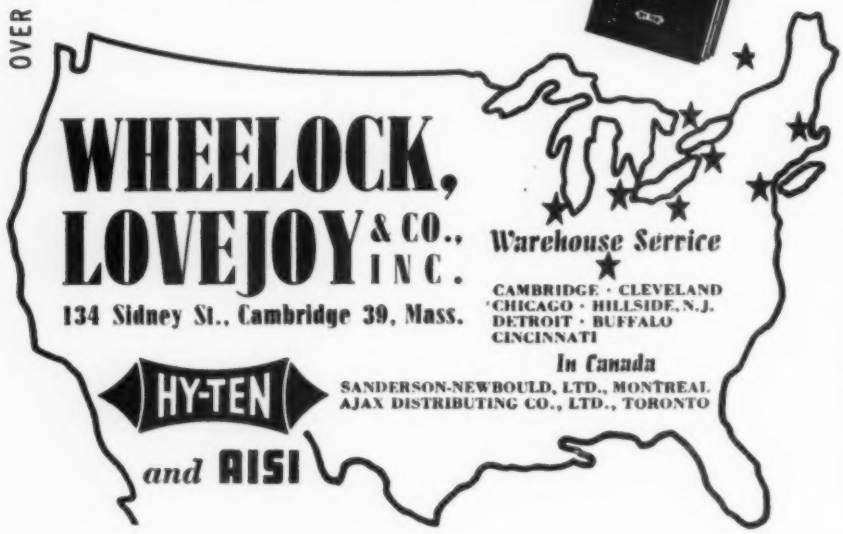

Broadened X-Ray Lines of Martensite*

THE NATURE of X-ray diffraction lines given by martensite and the disappointing results which arise in the photometry of lines unless they are sharp and fairly strong have discouraged many workers from using this type of analysis in obtaining evidence of the nature of the martensite structure. Diffraction lines obtained from martensite are noted for their diffuseness and, of course, they cannot be made sharp by annealing since the martensite decomposes. Two of the chief factors which may contribute to this line broadening are stress pattern and particle size, and the latter has generally been considered responsible for this effect in martensite. However, it is well known that the austenite-to-martensite transformation gives rise to a pattern of balanced local internal stresses and this work was designed to determine whether these stresses could alone account for the observed line broadening. If we let β be the breadth of any line and Θ the Bragg angle at which it appears, then the relation between β and Θ will give an indication of which factor is responsible for the line broadening. If it is caused by small particles, β should be proportional to sec θ, whereas, if the microstress is responsible, β should be proportional to tan Θ.

Experiments were carried out on one industrial high-carbon steel and two high-purity iron carbon alloys. The latter were made by melting Hilger's electrolytic iron and Hilger's graphite together in a magnesia crucible in a hydrogen atmosphere and allowing the resulting alloy to cool *in vacuo*. Microscopic examination showed the alloys to be homogeneous, but one was homogenized 48 hr. at 1130° C. (2065° F.) before X-ray samples were taken. Rods 1 mm. square and 2 cm. long were taken from each of the three steels; they were sealed in evacuated silica tubes and quenched in water after holding 15 min. at 1050° C. (1920° F.). X-ray photographs of *(Cont. on p. 424)*

*Abstracted from "The Breadth of X-Ray Diffraction Lines From Martensite", by J. A. Wheeler and M. A. Jaswon, *Journal* of the Iron and Steel Institute, October 1947, p. 161-166.

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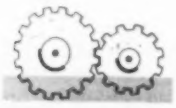

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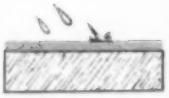

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...when they are made from acid- and corrosion-resistant Ampco Bronze and welded with Ampco-Trode 10 aluminum-bronze electrodes

Here's another process application for Ampco — this time in a brewery, one of the largest in the country. These pipes, made from grade 40 Ampcoloy, an engineered aluminum-bronze alloy, are 14 feet 7⅛ inches long and 8 inches in diameter. Eight separate pieces centrifugally cast form a complete pipe. These pieces with 11-inch end flanges are welded together with Ampco-Trode 10 aluminum-bronze electrodes. Ampco-Trode 10 was used because it has the same acid- and corrosion-resistant and physical properties as the parent metal.

This pipe is used because it does not produce cloudiness in the beer. It saves money for the brewery because it lasts indefinitely and does not affect the flavor.

Other process industries throughout the country are using large quantities of Ampco aluminum bronzes, too. They find that Ampco bronzes have many desirable service qualities not found in other anti-acid metals. High tensile strength. Good ductility. Less weight. Favorable hardness. This popular aluminum-bronze alloy resists corrosion, erosion, cavitation — it handles successfully such liquids as acids, alkaline solutions, sea water, mine waters, petroleum sludge, hot brine, and food-product liquors.

Save yourself money, trouble, and time — send your processing problems to us. Our engineers can help you adapt assemblies fabricated out of Ampco Metal to your requirements. Write for our latest descriptive bulletins.

AMPCO TRADE MARK

Ampco-Trode 10 is a product of

Ampco Metal, Inc.

Department MP-3 Milwaukee 4, Wis.

P-30

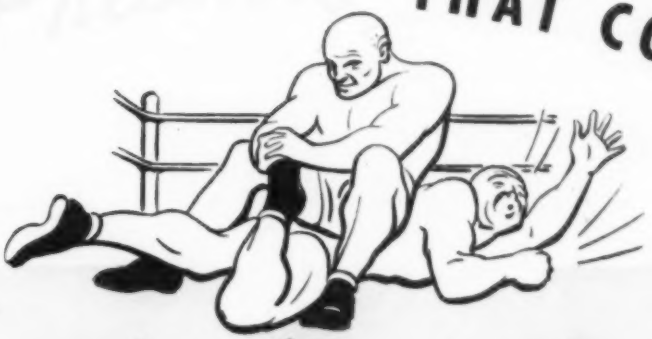
Martensite

(From p. 422) the martensite rods were taken in a 9-cm. Debye-Scherrer powder camera using K_α radiation of iron. The rods were tempered 20 hr. at 600° C. (1100° F.) to produce stress-free ferrite, and X-ray photographs were again taken in order to evaluate the correction necessary for experimental line broadening. Finally, the carbon content of each rod was determined by a microcombustion method and was found to be 1.35 and 1.43%, respectively, in the two experimental alloys and 1.35% in the industrial steel. The X-ray photographs were photometered with a Dobson-type photometer, and the linearity of the blackening-intensity curve was established by calibration strips put on the film by a rotating stepped sector.

Intensity readings were plotted against distance along the film, and the background was found by interpolating between the readings of the background on either side of each pair of lines. Where the martensite doublets were overlapped by austenite lines, correction was made by subtracting the calculated intensity distribution due to the austenite. The separate lines of each martensite doublet were then resolved by assuming that the martensite lines unaffected by austenite overlap are symmetrical about their peak values. Areas under the corrected intensity-distribution curves were calculated using Simpson's approximation, and the integral line breadth was calculated from the Laue formula. Finally, the correction for instrumental broadening was made from measurements of the ferrite lines obtained from the X-ray photographs of the tempered specimens.

Results obtained on the three martensite doublets M2, M6, and M8 (where the numbers indicate the sum of the squares of the line indices) showed the line breadth was proportional to the tangent of the Bragg angle of reflection. This means that a microstress mechanism is responsible for the line broadening. Breadths of the two lines of the martensite doublet M4 appeared higher, but this is explained by assuming that Young's modulus in the [100] direction in martensite is less than in the directions perpendicular to the planes giving rise to the other diffraction lines. *(Cont. on p. 426)*

IT'S THE Pressure THAT COUNTS...



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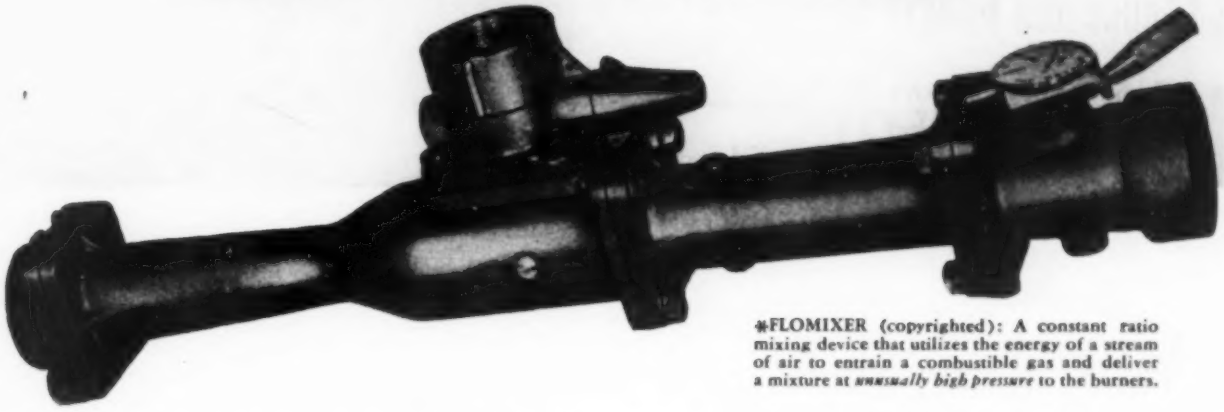

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Gas combustion engineers who have seen the Bryant Flomixer in action sing its praises. They like the way it "fits" a job—its flexibility of arrangement without the necessity of special parts, and its *dependable delivery of extreme high pressure mixtures.*

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Martensite

(Abstract starts on p. 422)

If particle size is assumed to be the only factor causing line broadening, calculation by the Scherrer formula shows that the average crystallite dimension will be about 7 interatomic distances which appears to be too small to be stable. On the other hand, if we assume, as this work indicates, that microstresses are responsible for line broadening, then the average stress in the structure can be shown to be about 210,000 psi., which is a reasonable figure.

Uncertainty of this type of analysis prevents the conclusion that there is no possibility of line broadening due to small particles, but the balanced local internal stresses, which the martensitic structure is known to contain, are in themselves adequate to account for the observed line breadths and must in any case be responsible for the major part of the broadening.

Electrolytic Mn for Steelmaking*

A PILOT PLANT for the study of methods of recovering manganese from American ores has been in operation at Boulder City, Nev., since 1941, and in that time over 750 tons of pure metal has been recovered. The process was perfected while studying the wad ores from nearby Three Kids Mine; R.I. 4163 describes work on ore from four other mining districts and from the American ore stockpiled during the war by Metals Reserve. Principal interest is in the calcareous nodules from Chamberlain, So. Dak., the almost limitless deposit whose mining and concentration problems have received so much attention (see *Metal Progress* for August 1946, p. 320). *(Cont. on p. 428)*

*Summary of two Bureau of Mines Reports of Investigations: R.I. 4163, "Electrowinning of Manganese from Domestic Ores", by J. H. Jacobs, and R.I. 4157, "Electrolytic Manganese in Acid and Basic Electric Steel Foundry Practice and Basic Steel Ingot Production", by F. Sillers, Jr., R. T. C. Rasmussen, and J. H. Jacobs.

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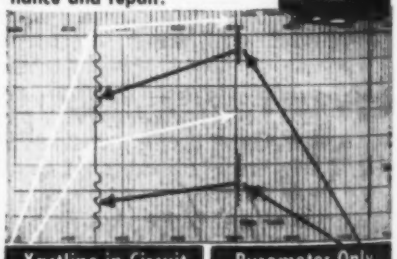

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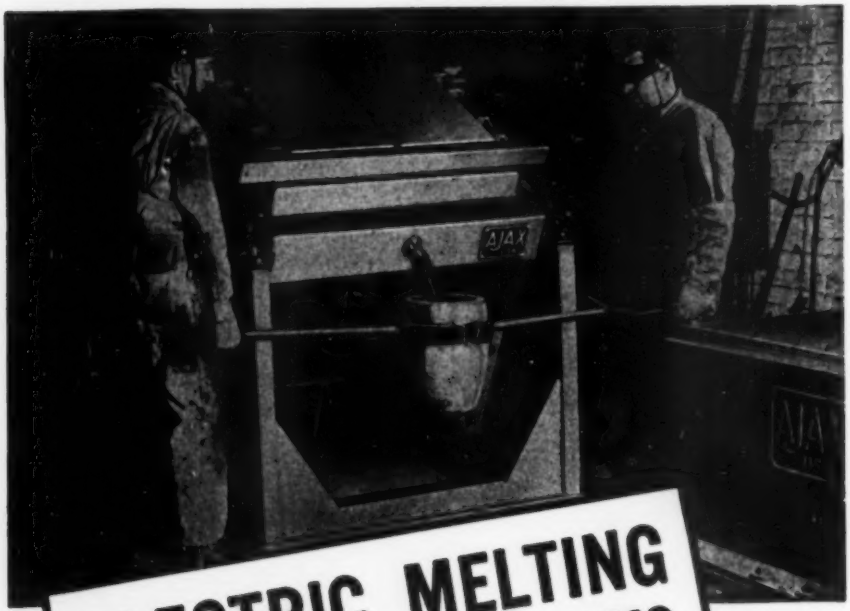

ELECTRIC MELTING of ALUMINUM ALLOYS

No Longer a Luxury

Aluminum alloy iron-core induction melting furnaces, the first of this kind capable of continuous operation, have been developed at Ajax's Experimental Foundry (see photo upper right). Simplified cleaning methods and improved design of melting channels have resulted in increased lining life and reduced maintenance cost.

Job of melting 300 pounds per hour requires 60 kw. unit (see photo above) occupying about 4' x 4' x 4' space, requiring no foundations and provided with a self-contained internally wired control cubicle, including potentiometer type temperature controller. Operating cost from 40 to 70 cents per hour, with maintenance items almost negligible.

Another unit of 20 kw. capacity is finding wide acceptance as holding furnace in die casting and permanent mold work. Space required is about 3' x 3' x 3', no foundations, self-contained control cubicle. Operating cost from 8 to 12 cents per hour. Metal charge of crucible is 300 pounds.

X-ray investigation carried out on metal processed in Ajax induction furnace proves that accurate (free of time lag) temperature control, typical of these furnaces, allows casting consistently at lowest and most adequate temperatures necessary for sound castings, all of which results in considerable reduction of rejects.

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TRENTON 7, N. J.

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AJAX ELECTROTHERMIC CORP., Ajax Northrup High Frequency Induction Furnaces
AJAX ELECTRIC CO., INC., The Ajax-Hultgren Electric Salt Bath Furnace
AJAX ELECTRIC FURNACE CORP., Ajax-Wyatt Induction Furnaces for Melting

Pure Manganese

(Continued from p. 426)

The electrolytic process in use at Boulder City required very little modification to handle the Chamberlain nodules successfully. An important economic advantage was that they required no roasting after crushing and prior to leaching. Leaching was done in exhausted anolyte from the cells, fortified with H_2SO_4 and $(NH_4)_2SO_4$. After agitation for 1 hr. the mass was neutralized with NH_4OH, thickened, filtered, and washed. Solutions were then purified from most contaminating metals by H_2S (only 0.05 g. per liter was needed), and again filtered. Colloidal sulphur and interfering traces of arsenic and molybdenum were removed by adding 0.1 g. per liter of ferrous sulphate, aeration (which precipitates ferric hydroxide), aging, and filtration.

The electrolytic cell and its operation, as well as the removal of magnesium before it builds up in the electrolyte to troublesome proportions, is described in R.I. 4163. Current efficiency is 62 to 66%. Cathodes are Type 316 stainless steel, buffed smooth every other day. Anodes are cast slabs of lead (1% Ag), drilled with 1⅝-in. holes at close centers. Cathodes are removed at 24-hr. intervals, dipped in 1% sodium dichromate to prevent oxidation of the deposit, and stripped by rapping with a rubber mallet. Total impurities in the manganese come to 0.030%; carbon being less than 0.003%, sulphur 0.015%.

No cost estimates for operation on a commercial scale are included.

Electrolytic manganese has already found considerable use, commercially, in the production of special copper, nickel, zinc, or aluminum alloys, in competition with metal of 96 to 98% purity made by electrothermal or aluminothermic methods. Much work has been done — principally by research metallurgists on the Bureau of Mines staff — on the interesting properties of new alloys wherein manganese is the principal metal. The overwhelming consumption, of course, is in the steel industry; about 70 steel works and foundries have used quantities of the metal in regular production of stainless steels, acid steel castings, and low-carbon steel. *(To p. 430)*

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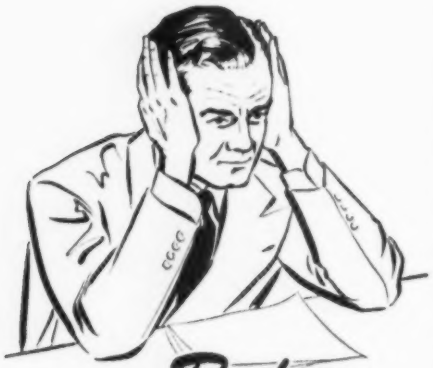
Photo Courtesy of Shell Oil Co., Inc.

3569

International Graphite & Electrode Corp.

SAINT MARYS, PA.



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Pure Manganese

(Starts on p. 426) Results have been reported in Bureau of Mines publications R.I. 3829, 3830, 3911, 4078. (R.I. 3830 on acid steel was summarized in *Metal Progress* for December 1946, p. 1250.)

Heat logs and general results for several melts of basic steel are given in R.I. 4157. It is far less difficult to incorporate the cathode chips into a basic steel than in an acid bath, since the slag is reducing and losses of manganese to slag are always small.

At Adirondack Foundries & Steel, Inc., of Watervliet, N. Y., 20 lb. manganese was added to a 5½-ton basic electric heat immediately after slag-off and 30 lb. added with the recarburizer (pig iron) and ferrosilicon 20 min. before tapping. Specification was for 0.25% C and 0.65% Mn. Efficiency of recovery was 91%; C. L. Richards, metallurgist, stated that the results compared very favorably with regular practice using ferro. The same steel was made in a 15-ton basic electric furnace heat at General Metals Corp., Oakland, Calif. 120 lb. of electrolytic manganese was shoveled in *after* the second or reducing slag was formed. The second small addition (36 lb.) was made with the ferrosilicon and aluminum 10 min. before tap. Recovery was 75%, as compared with 85% for standard ferro.

At Babcock & Wilcox Co. of Beaver Falls, a 15-ton basic heat of modified 52100 steel for high-duty ball bearings (where inclusion type and distribution are of importance) was made. 325 lb. electrolytic manganese was added after slag-off and 110 lb. before tap. Recovery was 100%. C. P. Church, plant metallurgist, reported that no essential difference was noted in the hot working of the steel, its annealing, or the deep etch test. Under these circumstances, pure manganese would probably be used if costs were competitive.

Two 4-ton heats were made at Dodge Steel Co. of 1.20% Mn, 0.30% Cr, 0.30% Mo, 0.30% C, boron-treated steel castings for aircraft parts (heat treated to 125,000 psi.). Analysis was met by adding electrolytic manganese in the ladle. It was concluded that when orders of this analysis are so small that portions of a heat are required, secondary ladle additions of electrolytic manganese are desirable.

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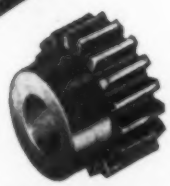
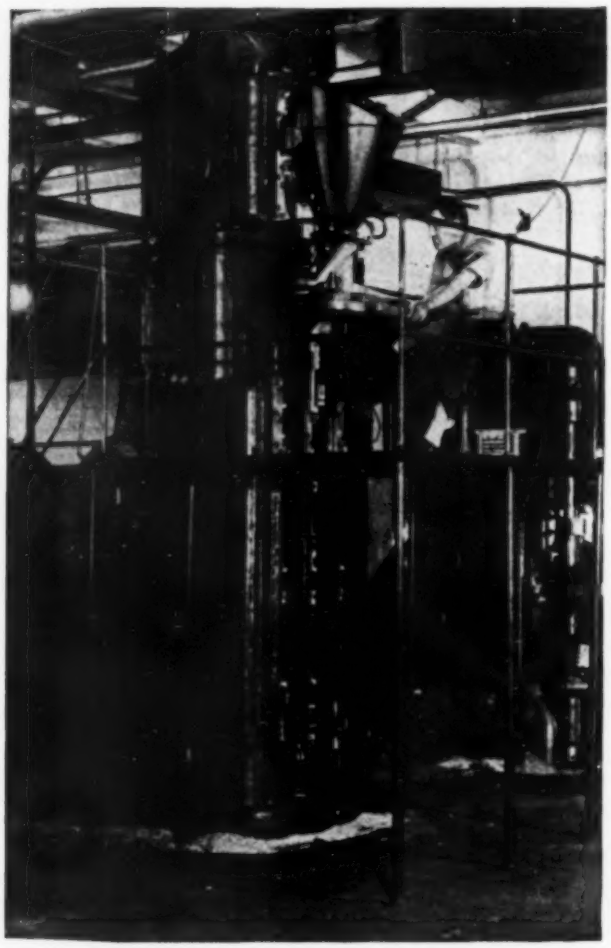


forms machine parts on STOKES PRESSES



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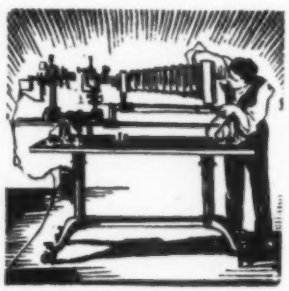
Graphite Formation in Cast Iron*

THE metallurgical potentialities of gray cast irons will not be realized until the graphite formation during solidification is understood and controlled. Cast irons are perhaps the most complex of alloys and unique in their sensitivity to rate of cooling.

Graphitic carbon is ordinarily distributed in two ways—as lamellar or flake graphite, and in a finely divided form referred to as supercooled, reticular, or dendritic. There is evidence for the existence of other forms of graphite in gray irons, including the nodular or spherulitic type hitherto obtained only by heat treatment of white iron. The preliminary work will be described which has led to the production of nodular graphite in the as-cast state without any heat treatment.

The optical anisotropy of graphite flakes can be studied by the polarizing microscope. The color of a graphite crystallite will vary



twice from light brown to black as the specimen is rotated through 360°. Owing to this reflex pleochroism it has been possible to show that many graphite flakes have complex needle-like structures internally and are usually aggregates of interlacing crystals. Graphite spherulites consist of radially oriented crystallites growing from a common center.

The generally accepted facts relating to graphite formation in cast irons may be considered with reference to the ternary iron-carbon-silicon system. The finally solidifying graphite-austenite complex is usually *(Cont. on p. 434)*

*Abstracted from "Graphite Formation in Grey Cast Iron", by H. Morrogh and W. J. Williams. *Engineering*, Aug. 8, 1947, p. 141 and Aug. 15, 1947, p. 166.

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